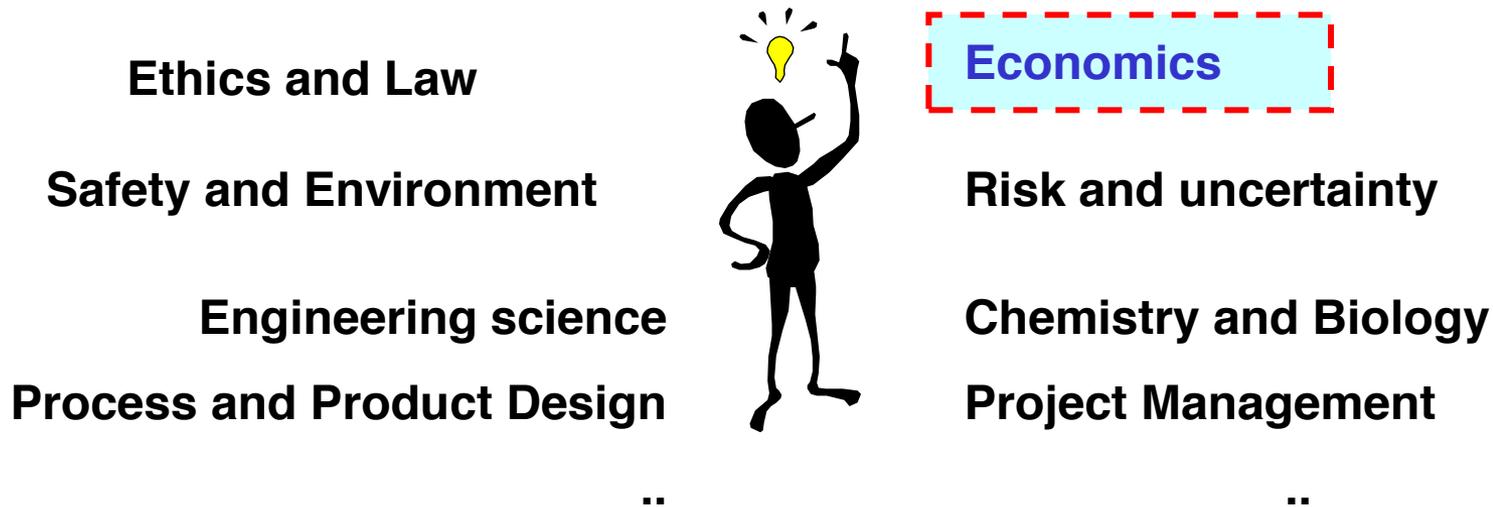


# Class notes for ChE 4N04 Engineering Economics section



**We all must be able to apply basic concepts of economics because economics plays an important role in every engineering decision.**

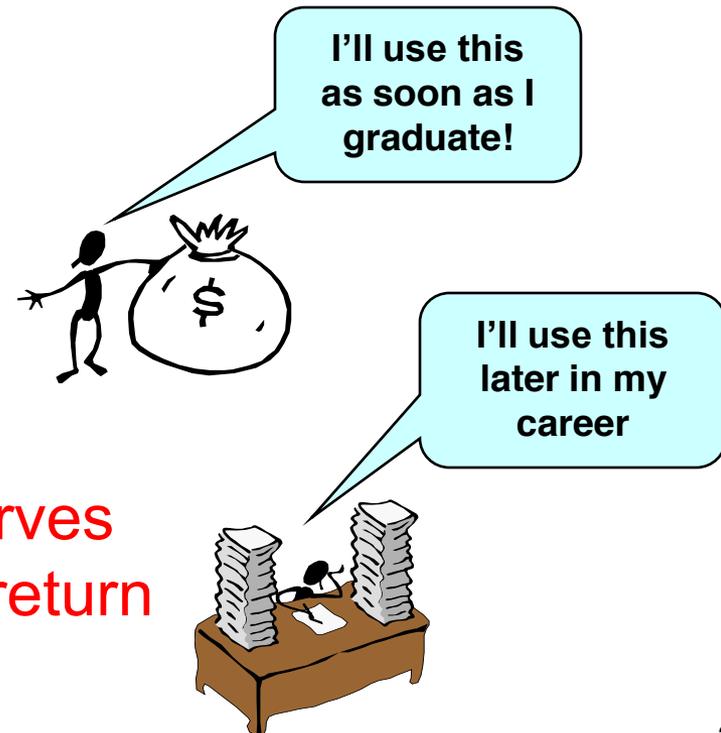
# Course principles have many applications

## Engineering Economics

- Evaluate profitability of alternative investments

## Personal Finance

- When to buy that new car!
- Determine proper level of borrowing and saving
- Calculate income taxes



## Corporate Finance

- Provide adequate cash reserves
- Determine minimum rate of return

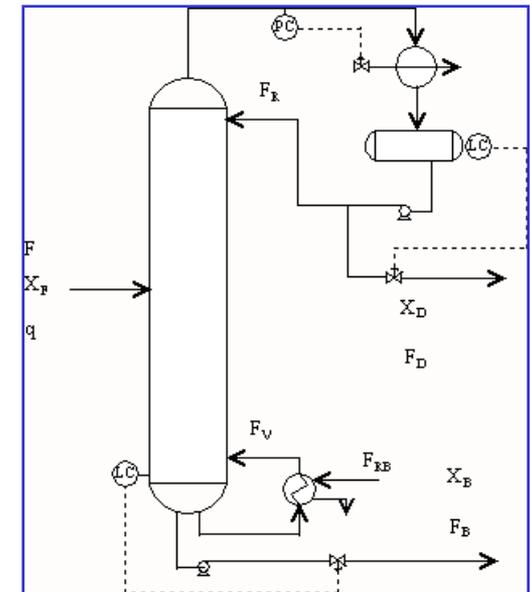
# Your first task at your new job

**Supervisor to you:** We want to increase our production rate by 35%, but the distillation tower is at its maximum capacity (liquid and vapour flows).

**Evaluate the following feasible alternatives and determine the most financially attractive.**

*After some creative brainstorming ...*

1. Build a parallel distillation tower
2. Replace trays with packing
3. Increase the number of trays
4. Contract the extra production to another company
5. Change operating conditions



What is the best choice?



# Roadmap for engineering economics topic

- **Four major topics**

- Time value of money
- Quantitative measures of profitability
- Selecting from among alternatives
- Cost estimating



**Able to evaluate potential projects and select the best**

- **Lecture exercises and thought questions**
- **Class workshop**
- **Midterm (individual)**
- **Application in the SDL Project**

# Four major topics in engineering economics

## 1. Time value of money

- How do we compare \$ at different times?

## 2. Quantitative measures of profitability

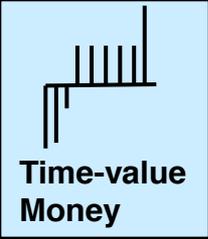
- How do we determine the “profit” or “financial attractiveness” from an investment?

## 3. Systematic comparison of alternatives

- How do we ensure that we select the “best” investment?

## 4. Estimation of costs

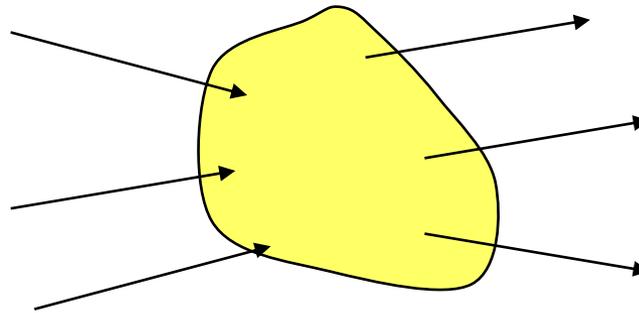
- How do we determine the costs before we buy?



# Time value of money

Let's use our modeling skills to determine a “*money balance*”

**Revenues or incomes flow into the system, e.g.**

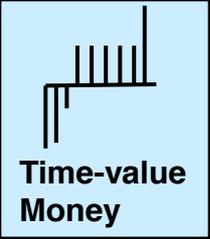


**Expenditures or costs flow out of the system, e.g.,**

- Product sales
- Equipment sales
- Licensing fees

- Feed costs
- Fuel and electricity
- Employee salaries

**Important definition:** **Cash flows** are transfers of money that cross the system boundary. The system is typically a “project”.



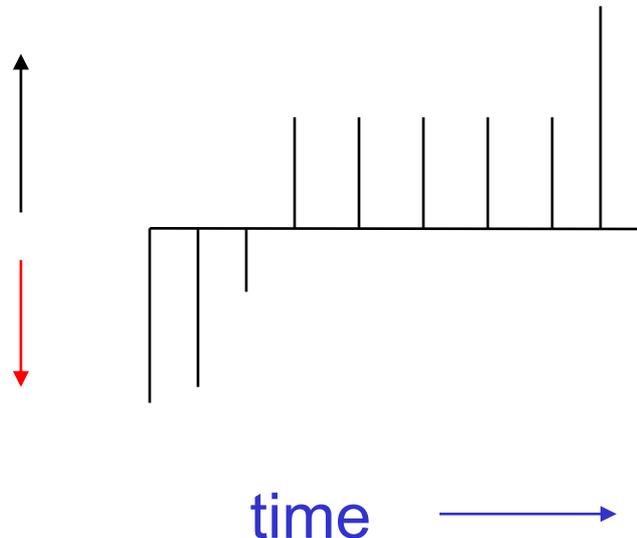
# Time value of money

## Cash flows occur over time.

We sum the revenues and expenditures within each time period to give the net cash flow at a time. We plot these in a cash flow diagram.

## Cash flow diagram

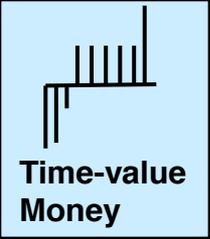
**Positive cash flow**  
**Negative cash flow**



**Periods are numbered from 0 to the end of analysis.**

Period can be any time length; often one year for engineering projects

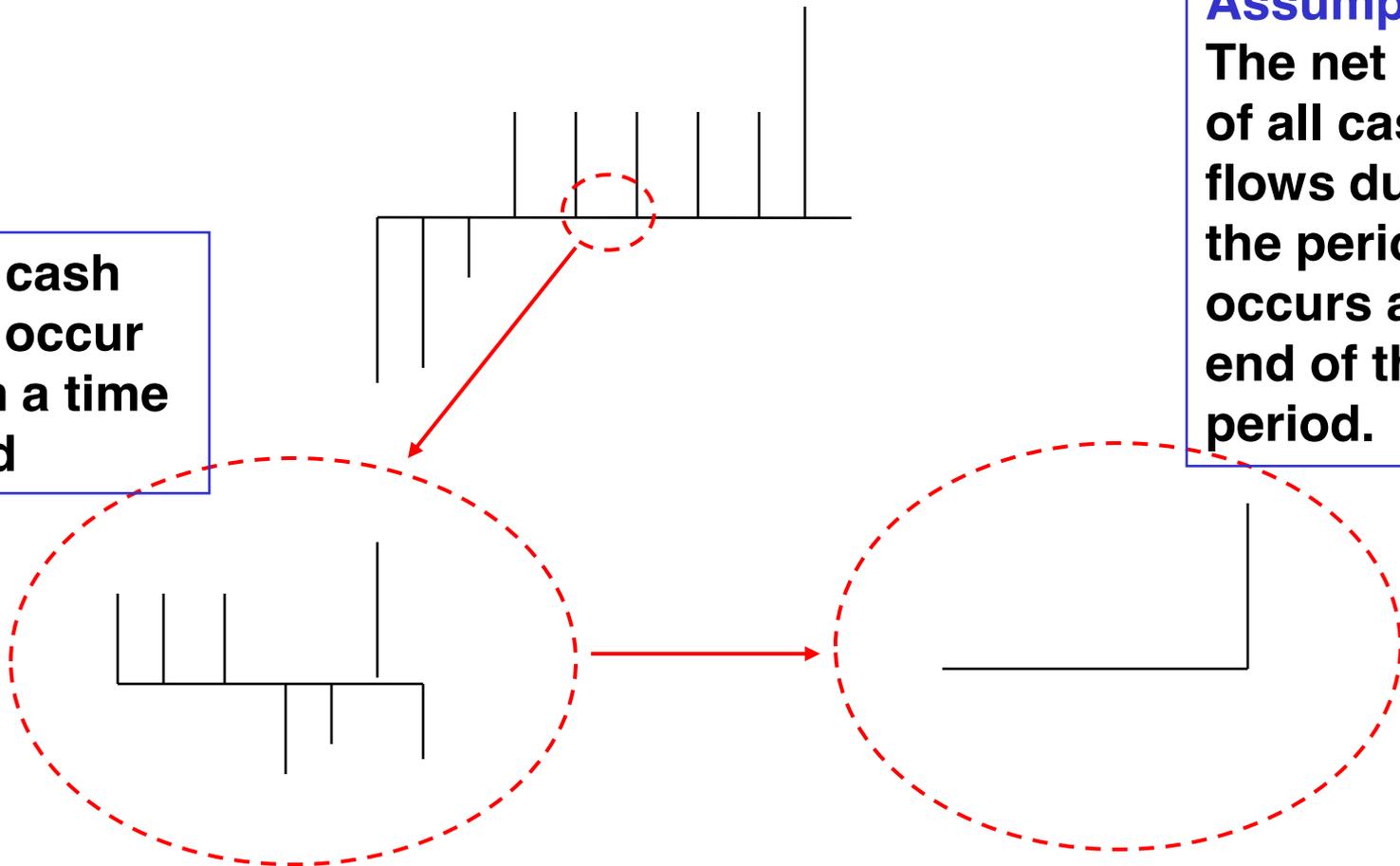
Cash flows in units of money (\$)



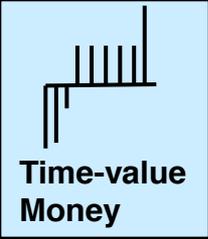
# Time value of money

## Cash flow diagram and analysis

Many cash flows occur within a time period



**Assumption:**  
The net sum of all cash flows during the period occurs at the end of the period.

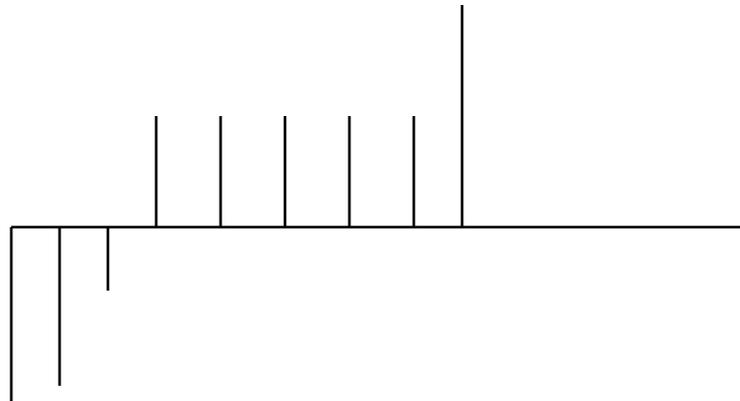


# Time value of money

We plot the end-of-period, or the cumulative cash flows

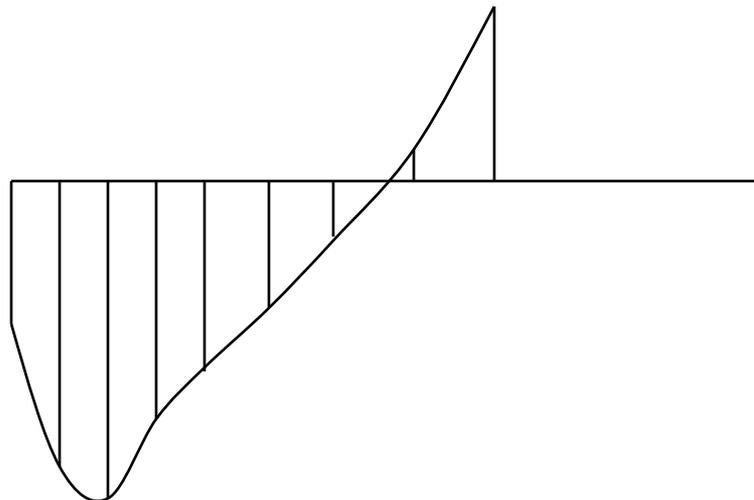
## Cash flow diagram

(at each period)

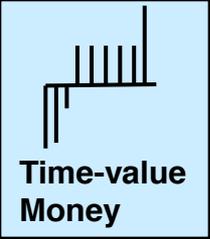


## Cumulative cash flow diagram

(just the cumulative sum of the above plot)



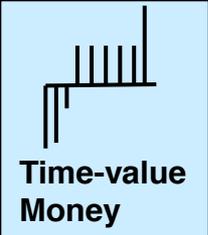
**We'll use both, with the top plot used more often.**



# Time value of money

Draw a cash flow diagram for life from age 10 to age 40 with periods of 1 year

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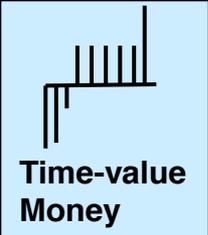


# Time value of money

**Key question:** Why is there a “time value of money”?

**Class exercise:** A family member asks you to lend her \$100. She promises to pay you exactly three years later. She will give you \$100 then.

***Is this a good financial proposition? Why?***



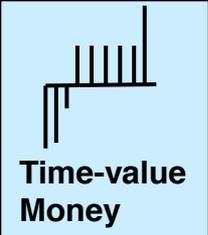
# Time value of money

## Why is there a “time value”?

- **The owner of money must defer its use**
- **The owner incurs risk**

**Thus, money in the future is worth less than money now.**

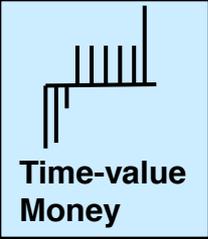
We must take this into account, as our employer's money will almost always be spent over a long period of time.



# Time value of money

## How do we characterize time value?

- We use an **interest rate**, so that the effect of time is proportional to the total amount of money involved.

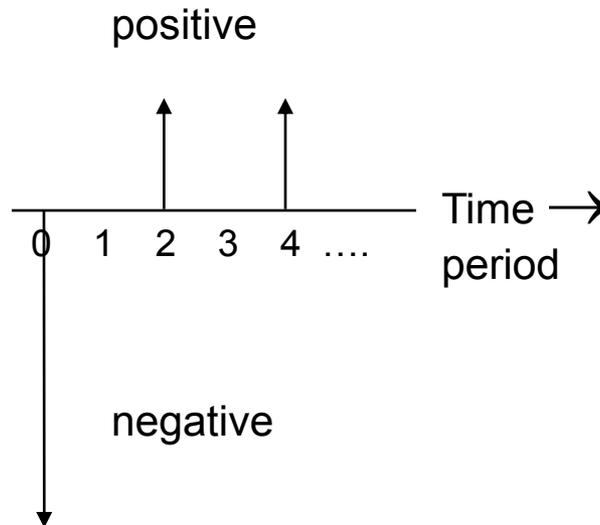


# Time value of money

We will use cash flow diagrams to summarize the behaviour of the system.

We need to calculate the value of all cash flows at the same time to make economic analyses.

Cash  
flow  
at each  
period  
(\$)

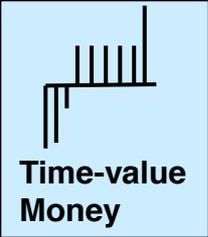


$P$  = present value (period = 0)

$F$  = future value (period > 0)

$i$  = interest rate

$n$  = number of periods  
between present and future



# Time value of money

## Example 1:

We would like a future amount  $F = \$1000$

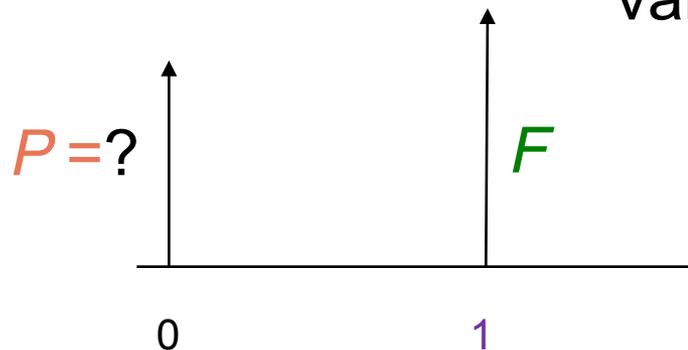
But we have only  $P = \$800$  to invest now.

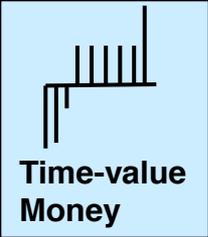
What interest rate is required to obtain  $F$  at  $n = 1$  year from now?

## Example 2:

We would like a future amount  $F = \$1000$  at  $n = 1$  year from now.

Given an interest rate  $i = 0.04$  [4%], how much should we invest today, called the present value,  $P$ ?





# Time value of money

Determine the relationships between  $P$  and  $F$  for  $n$  time periods, with compound interest rate  $i$

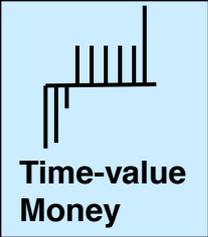


$$F_n = P ( 1 + i )^n$$

What is the present value of a revenue of  $F = \$1000$  at time  $n$  for each year  $n = 1, 2 \dots 10$  at 10% per year time value of money?

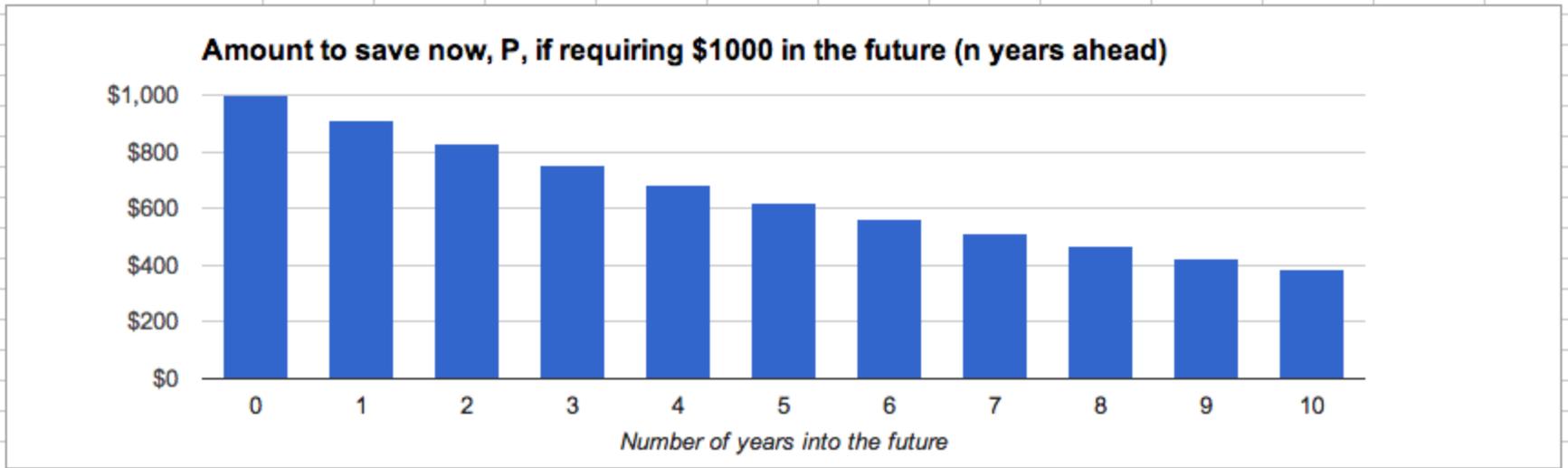
*Asked another way ...*

If you want to have  $F = \$1000$  in  $n = 1, 2, \dots 10$  years from now, how much do you have to invest right now, if interest rates remain at 10% per year?

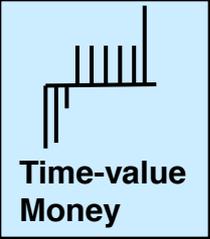


# Time value of money

Amount in the future (F)	\$1,000 (desired)										
Interest rate (i)	0.1										
Period, n	0	1	2	3	4	5	6	7	8	9	10
Present value required (P)	\$1,000	\$909	\$826	\$751	\$683	\$621	\$564	\$513	\$467	\$424	\$386

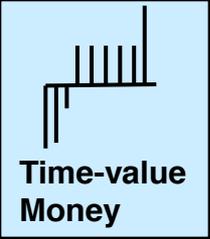


*Interpretation* : \$621 right now ( $n=0$ ) has the equivalent worth of what \$1000 will have 6 years ( $n=5$ ) from now, at interest rates of 10%.



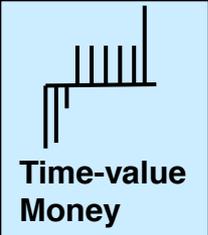
# Time value of money

**IGNORE**



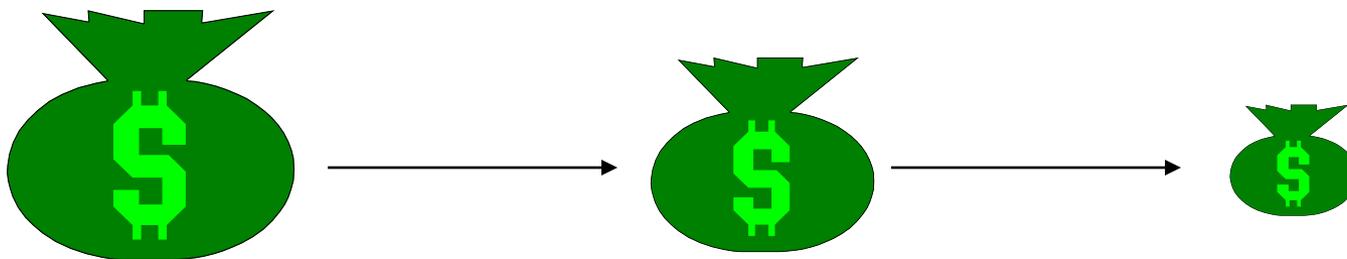
# Time value of money

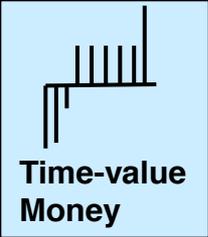
**IGNORE**



# Time value of money

- Since money has a time value, money in the future has less value. We will characterize this decrease with the “time value of money”.
- For a worthwhile investment, the net income in the future must be greater than the original expense.



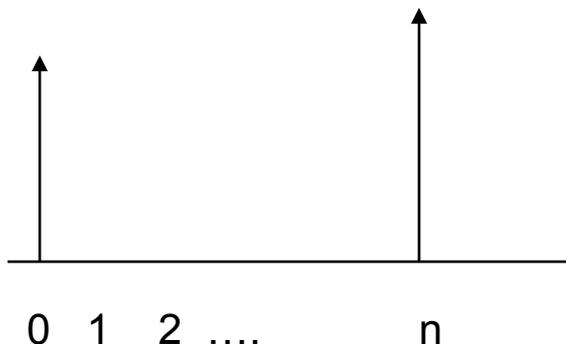


# Time value of money

**Associated use of interest rates:** When we place money in the bank, the bank increases the amount in our account according to an interest rate. This is payment for the bank using our money.

**Initial  
balance**

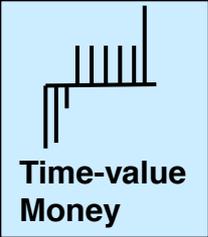
**Future  
balance = ?**



How do we calculate the future amount in our account?

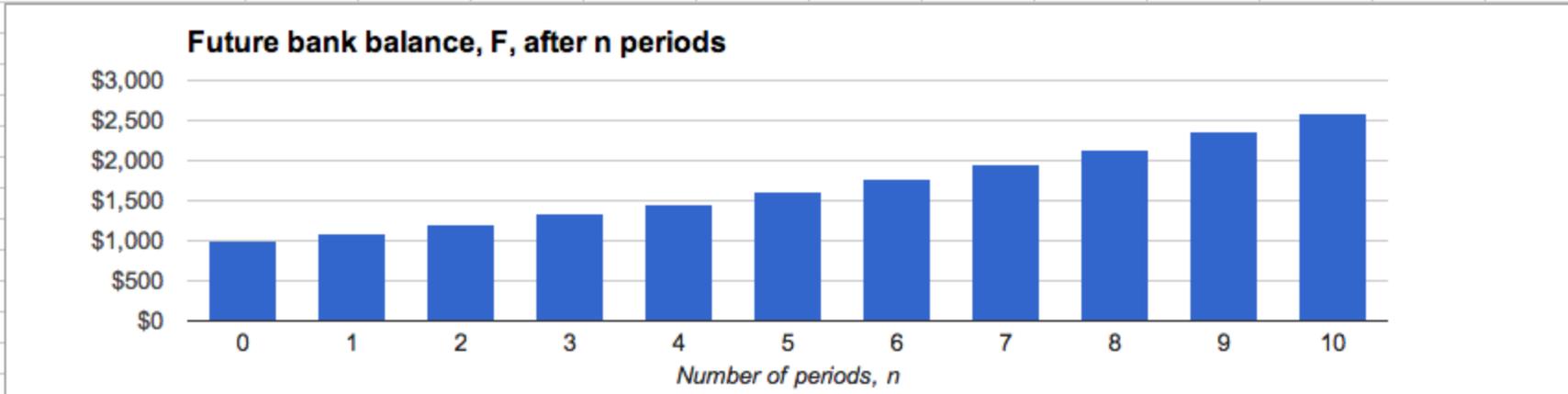
$$\text{Future balance} = P (1 + i)^n$$

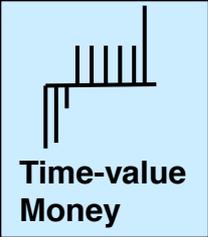
What is the amount in your account ten years after depositing \$1000 at 10% per year interest rate?



# Time value of money

<b>Amount invested (P)</b>	\$1,000										
<b>Interest rate (i)</b>	0.1										
<b>Period, n</b>	0	1	2	3	4	5	6	7	8	9	10
<b>Bank balance, F</b>	\$1,000	\$1,100	\$1,210	\$1,331	\$1,464	\$1,611	\$1,772	\$1,949	\$2,144	\$2,358	\$2,594



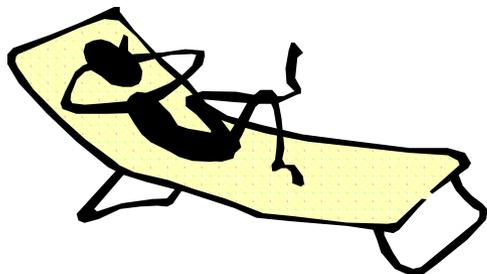


# Time value of money

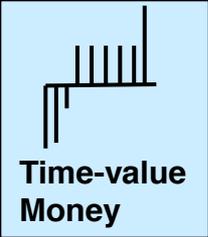
If you want to get rich, just invest and **wait**

Invest \$10,000/yr at 5% is worth after 35 years: \$ 948,000  
after 40 years: \$ 1,268,000  
after 45 years: \$ 1,677,000\*

\* This is close to the number we discussed at tutorial on Monday

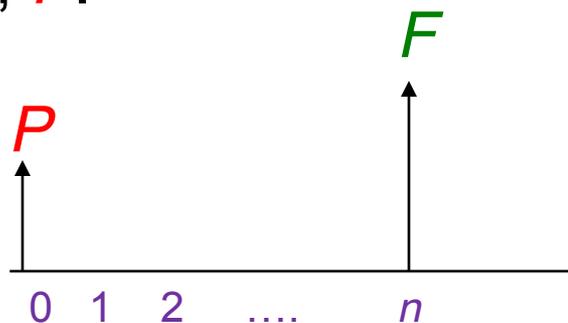


*“Compound interest is the eighth wonder of the world. He who understands it, earns it ... he who doesn't ... **pays it.**” – Albert Einstein*



# Time value of money

We can consider inflation,  $i$ , in a similar way. An amount of money in the future ( $F$ ), is worth less than in the present,  $P$ .



$$F_n = P (1 + i)^n$$

*Asked another way ...*

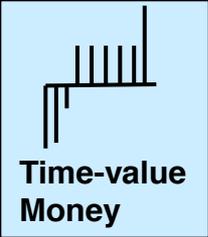
What is the **present value** of  $F = \$1000$  at time =  $n$

for each year ( $n = 1$  to  $10$ )

at **10% per year time value** of money?

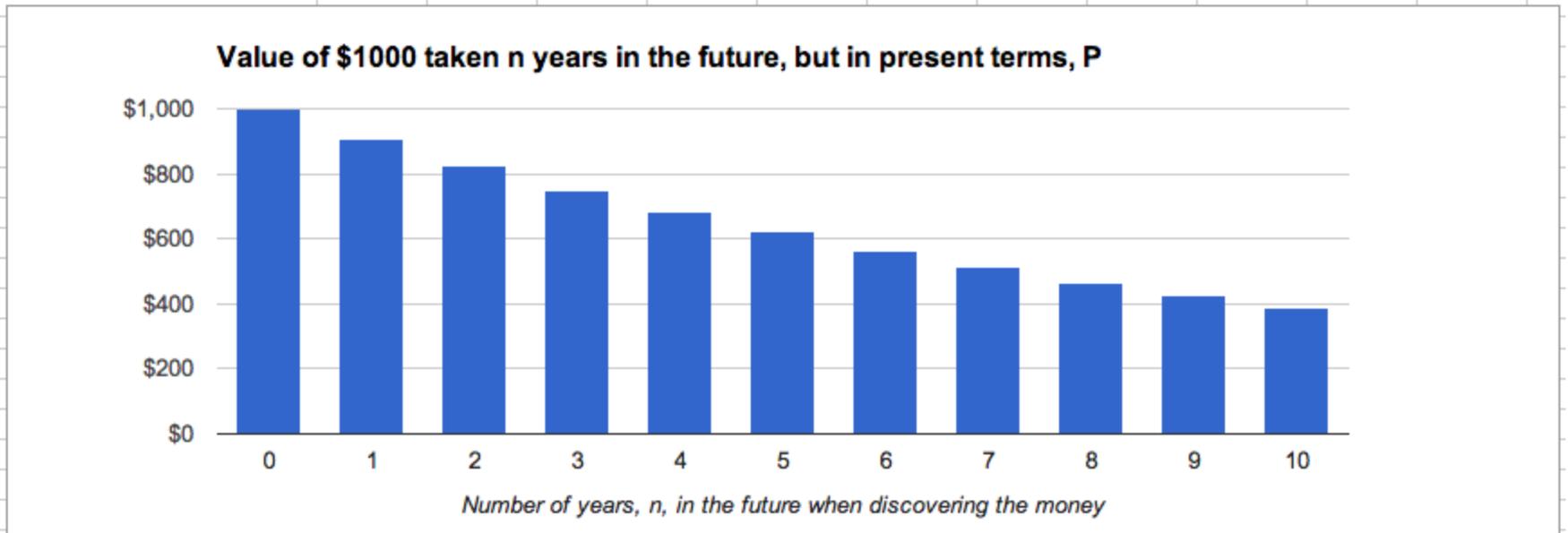
In  $n = 1, 2, \dots, 10$  years from now you discover  $F = \$1000$  under your mattress, and you can go buy goods with those dollars.

How much would those same goods have cost, **in today's dollars** if **inflation was 10% per year**?

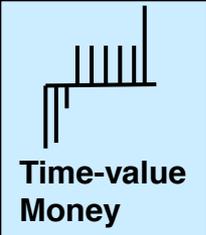


# Time value of money

Amount discovered later (F)	\$1,000											
Inflation rate (i)	0.1											
Period, n	0	1	2	3	4	5	6	7	8	9	10	
Value in present terms (P)	\$1,000	\$909	\$826	\$751	\$683	\$621	\$564	\$513	\$467	\$424	\$386	



*Interpretation* : If TVM (inflation) = 10%, then consider that something worth \$424 now is what you'll have to pay \$1000 for in 10 years ( $n=9$ ) from now.



# Time value of money

Economic and financial indicators

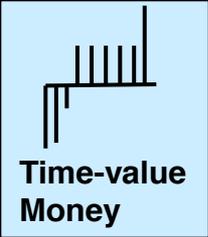
The Economist September 7th 2013

## Interest rates

### Economic data (2)

% change on year ago

	Current-account balance		Budget balance % of GDP 2013†	Interest rates, % 10-year gov't bonds, latest	Currency units, per \$	
	latest 12 months, \$bn	% of GDP 2013†			Sep 4th	year ago
United States	-425.7 Q1	-2.7	-4.0	2.89	-	-
China	+211.6 Q2	+2.1	-2.1	3.94 <sup>\$\$</sup>	6.12	6.35
Japan	+54.1 Jun	+1.2	-8.3	0.78	99.5	78.4
Britain	-96.7 Q1	-2.7	-7.6	2.95	0.64	0.63
Canada	-59.6 Q2	-3.1	-2.8	2.72	1.05	0.99
Euro area	+247.1 Jun	+1.8	-3.3	1.94	0.76	0.80
Austria	+9.7 Q1	+2.4	-3.0	2.37	0.76	0.80
Belgium	-8.7 Mar	-0.7	-3.1	2.82	0.76	0.80
France	-46.4 Jun	-2.1	-4.2	2.53	0.76	0.80
Germany	+244.5 Jun	+6.6	+0.3	1.94	0.76	0.80
Greece	-3.4 Jun	-0.8	-4.7	10.46	0.76	0.80
Italy	+5.9 Jun	+0.6	-3.5	4.42	0.76	0.80
Netherlands	+85.1 Q1	+8.1	-3.8	2.35	0.76	0.80
Spain	+8.7 Jun	+0.7	-7.2	4.43	0.76	0.80
Czech Republic	-3.8 Q2	-1.9	-2.9	2.58	19.5	19.8
Denmark	+18.2 Jun	+5.2	-2.6	2.13	5.65	5.93
Hungary	+3.0 Q1	+1.7	-3.0	6.59	228	227
Norway	+64.6 Q2	+12.9	+13.0	3.15	6.07	5.79
Poland	-9.3 Jun	-2.4	-3.9	4.80	3.24	3.34
Russia	+47.9 Q2	+2.5	-0.6	7.94	33.3	32.3
Sweden	+32.0 Q2	+7.1	-1.4	2.57	6.60	6.71
Switzerland	+77.6 Q1	+11.6	+0.2	1.18	0.94	0.96
Turkey	-53.6 Jun	-6.8	-2.2	10.02	2.06	1.82
Australia	-49.4 Q2	-3.1	-1.3	4.02	1.09	0.98
Hong Kong	+5.2 Q1	+0.9	+2.0	2.47	7.76	7.76
India	-87.8 Q1	-4.5	-5.1	8.39 <sup>†††</sup>	67.0	55.6
Indonesia	-28.8 Q2	-2.4	-2.9	na	11,065	9,571
Malaysia	+14.2 Q2	+5.8	-4.3	3.98	3.28	3.11
Pakistan	-2.3 Q2	-1.0	-8.8	12.10 <sup>†††</sup>	105	94.8
Singapore	+49.9 Q2	+18.3	+0.7	2.65	1.27	1.25
South Korea	+59.8 Jul	+3.5	+0.5	3.64	1,095	1,133
Taiwan	+52.8 Q2	+11.7	-1.9	1.73	29.8	29.9

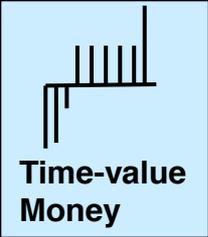


# Time value of money

**Class exercise:** Your bank account is the “system”. You have an initial revenue of \$4,000 and the following monthly revenues and expenditures, and the bank pays 5% interest per month.

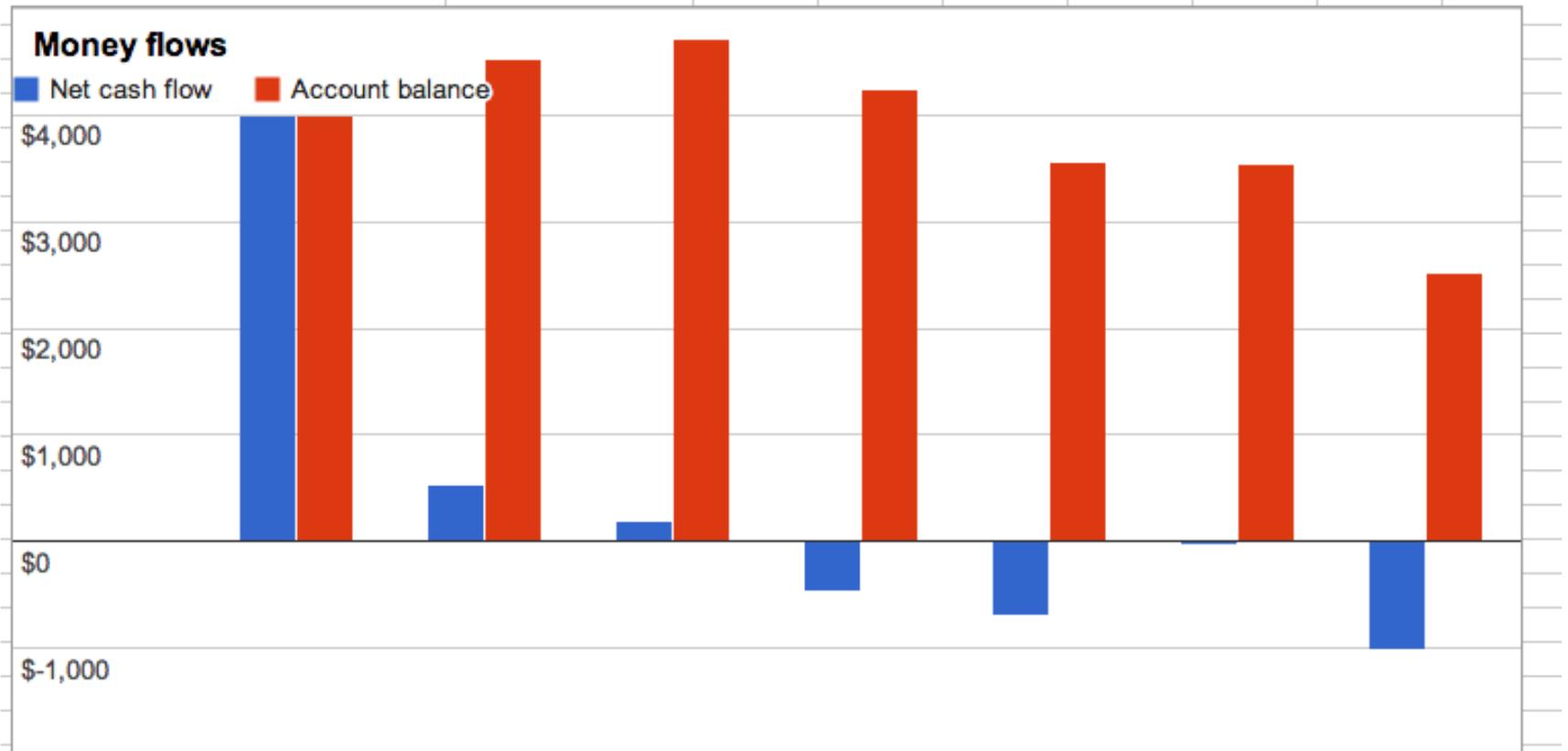
Plot the monthly balance *and* cash flow diagram for your bank account.

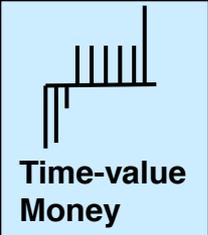
	Month	0	1	2	3	4	5	6
Revenues		\$4,000	\$530	\$530	\$0	\$0	\$0	\$0
Expenses		\$0	-\$200	-\$570	-\$700	-\$900	-\$200	-\$1,200



# Time value of money

	Month	0	1	2	3	4	5	6
Revenues	A	\$4,000	\$530	\$530	\$0	\$0	\$0	\$0
Expenses	B	\$0	-\$200	-\$570	-\$700	-\$900	-\$200	-\$1,200
Interest earned at 5% per month	$C = 0.05 \times E(n-1)$		\$200	\$227	\$236	\$213	\$178	\$177
Net cash flow	$D = A + B + C$	\$4,000	\$530	\$187	-\$464	-\$687	-\$22	-\$1,023
Account balance	$E = D + E(n-1)$	\$4,000	\$4,530	\$4,717	\$4,252	\$3,565	\$3,543	\$2,520



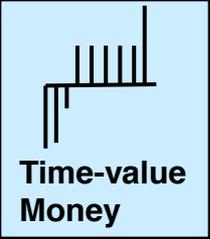


# Time value of money

**Now, let's relate the banking interest to the time value of money**

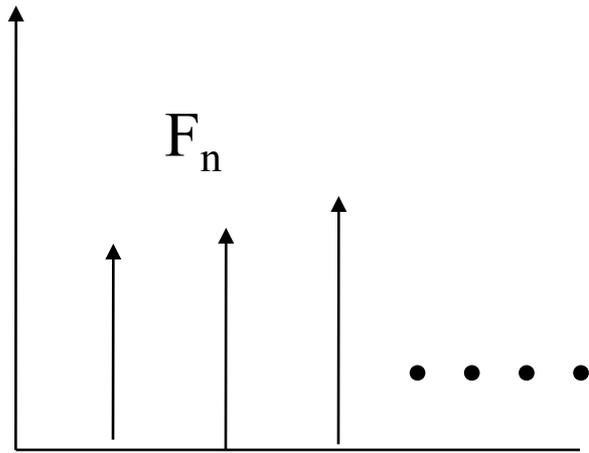
**Class exercise:** You deposit \$5000 in a bank account with an annual compound interest rate  $i^*$ . The time value of money is described by an interest rate  $i'$  (inflation rate).

Calculate the present value of the bank account after  $n$  years.



# Time value of money

$$C_0 = 5000$$



$$F_n = C_0 (1 + i^*)^n$$

Interest earned  
on the investment

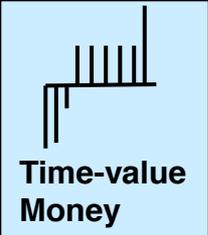
$$P = \frac{F_n}{(1 + i')^n}$$

Present value of  
the investment

$$P = C_0 \frac{(1 + i^*)^n}{(1 + i')^n}$$

What is the result if  $i^* = i'$ ?

How do we use this result to interpret the time-value of money?

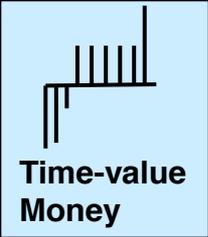


# Time value of money

## Class exercise

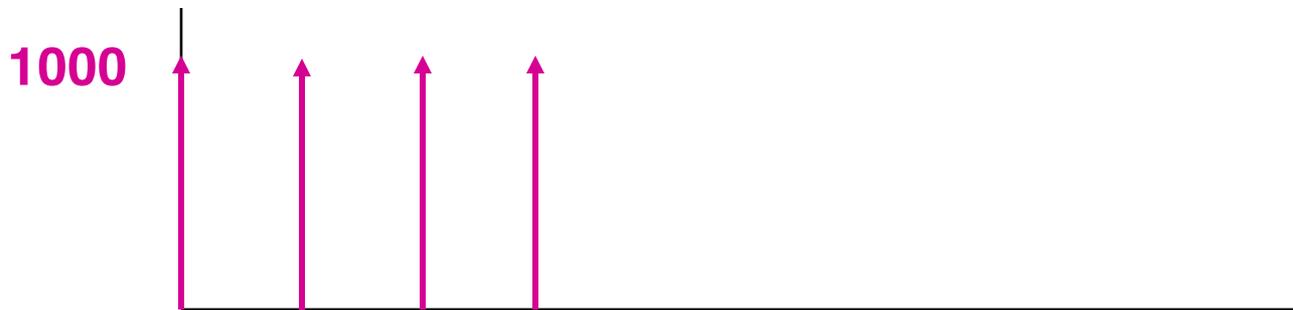
You have an income of \$1000 per year for each of the 4 years of your undergraduate studies.

- Draw a cash flow diagram
- Determine the value for this income in the beginning of the first year when the inflation rate (time value of money) is 10%.



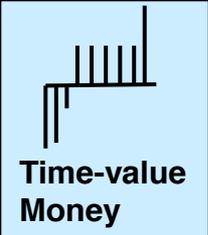
# Time value of money

## Class exercise



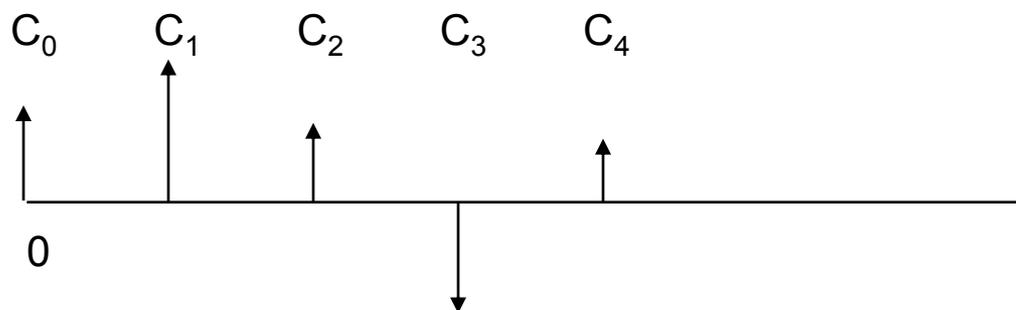
		Inflation rate, $i = 0.1$			
Period	$n$	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>
Cash flow in the period	$F_n$	\$1,000	\$1,000	\$1,000	\$1,000
Cash flow in present value terms	$P$	\$1,000	\$909	\$826	\$751
Cumulate cash flow in present value terms		<b>\$1,000</b>	<b>\$1,909</b>	<b>\$2,736</b>	<b>\$3,487</b>

*Interpretation:* You could have replaced the cash flow with one revenue of \$3487 at time period 0, that earned interest at 10%. Then make \$1000 withdrawals in each year from the bank account. The balance will be \$0 after the last withdrawal. Prove this interpretation for yourself in a spreadsheet.



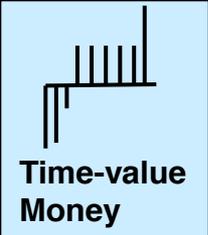
# Time value of money

**Look ahead:** We will be expressing values for different investments at the **same time** period for the purpose of comparison.



$$P = \frac{C_0}{(1+i)^0} + \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \frac{C_3}{(1+i)^3} + \frac{C_4}{(1+i)^4} + \dots$$

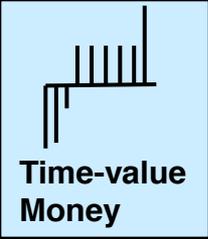
with  $C_n$  = cash flow at period  $n$  with a TVM rate of  $i$



# Time value of money

## Some thoughts

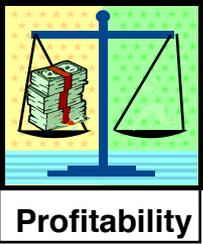
- **Interest factor tables:** Many tables are provided for relationships among  $P$ ,  $F$  and annuity values for specified interest rates and periods
- **Calculations:** Many projects have unequal cash flows. The time-value calculations are easily performed using spreadsheets like Excel.
- **Life-long applications:** These concepts are useful for personal finances (mortgage rate, credit card borrowing, and so forth).



# Time value of money

## Group learning / Self-directed learning

1. Determine the meanings of **simple**, **compound**, **nominal**, **effective** and **continuous** interest.
2. How would the equations used in this section be changed if the interest rate depended on the period?
3. You have a balance of \$4,000 on your credit card which has an interest rate of 24% (nominal, **compounded monthly**). How much do you have to pay per month to maintain your balance at \$4,000? How much do you have to pay per month to clear your debt in one year?
4. What is the meaning of the term “usury”? What is the history of charging interest for loans? Read up on Sharia compliant finance (finance without charging interest on loans).
5. Investigate the `=PV ( )` and `=FV ( )` functions in spreadsheet software

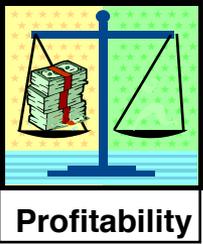


# Measures of profitability



1. Time value of money
2. Quantitative measures of profitability
3. Systematic comparison of alternatives
4. Estimation of costs

- We need a systematic method for **comparing** expenses and incomes at different times using the time value of money
- We need to compare the project profitability with a **minimum acceptable performance**
- Many measures are in use; we'll look at four.
  - Two are useful and commonly used by engineers
  - Two are **not recommended**, but are used in practice. We should know these as well.

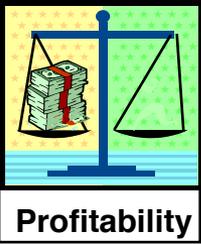


# Measures of profitability

The following organizations and decisions are not “profit based”; do they need measures of profitability?



- Universities
- Charities
- Governments
- For-profit companies when involved in
  - safety projects
  - environmental projects



# Measures of profitability

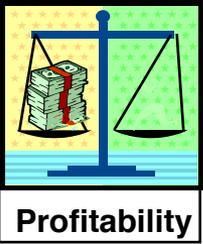
## Examples for each category



- Universities – e.g. rent or purchase computers
- Charities - Invest in fund raising
- Governments - In-house or outsource tasks
- For-profit companies when involved in

- safety projects
- environmental projects

Find project that satisfies goals at the lowest cost



# Measures of profitability

## Example

We can invest money yielding a 15% annually compounded return.

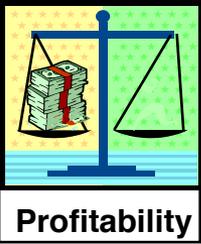
Compared to that, would the following project be financially attractive?

i.e. should we invest, or just park our money and earn the 15%?

Period	Cash Flow (\$)
0	-91,093
1	20,000
2	40,000
3	40,000
4	40,000
5	30,000

Don't know how to estimate the costs?  
Don't worry, we will cover the topic soon.





# Measures of profitability

## Payback time

- This measure is often used as a “quick and dirty” measure of profitability
- We use it in our daily lives: how long does it take to pay back for ...(car, vacation, new cell phone, *etc*)
- Also called *Payout Time*
- Defined in units of time (e.g. months or years)

**The time for the cumulative cash flow to achieve a value of \$0**

Usually (and in this course), payback time does not consider interest.



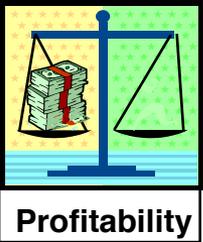
Profitability

# Measures of profitability

## Class exercise: Payback time

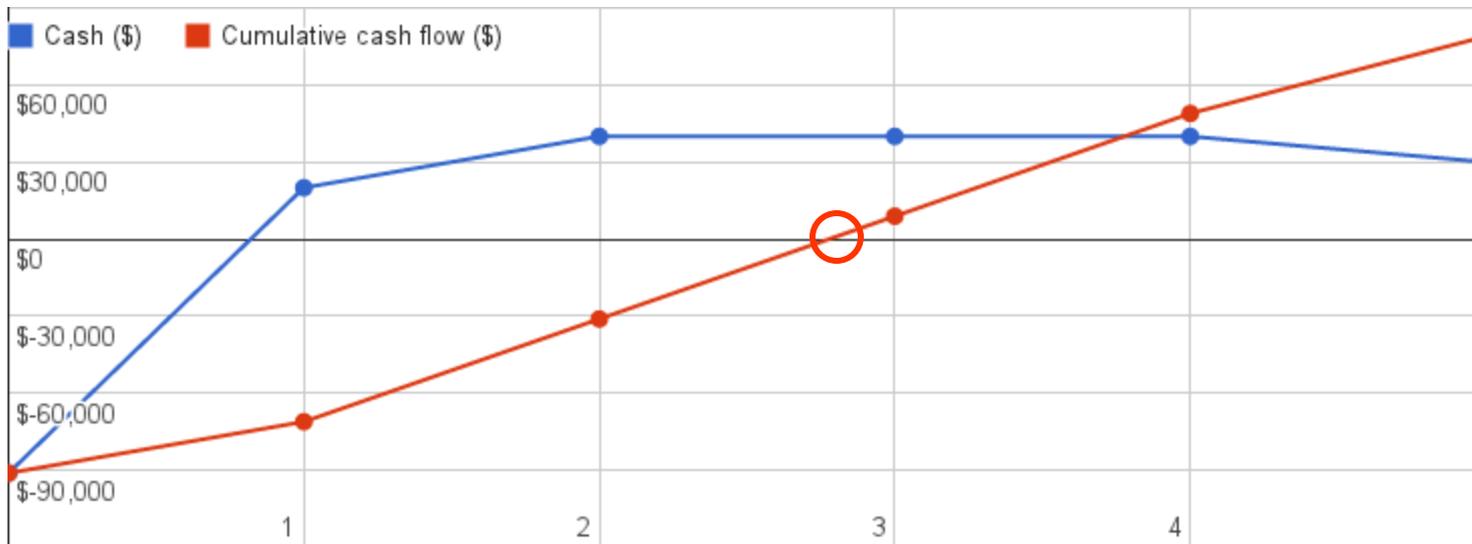
Determine the payback time for the cash flow defined in previous table

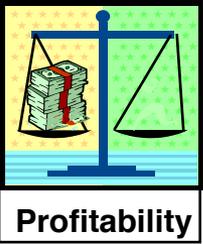
Period	Cash Flow (\$)
0	-91,093
1	20,000
2	40,000
3	40,000
4	40,000
5	30,000



# Measures of profitability

A plot (visual interpolation) used to determine the payback time





# Measures of profitability

- What is the **Payback time** for a project that involves an original investment of \$91,000 and provides an annual profit (positive cash flow) of \$34,000 per year over the first three years and no depreciation.

**Payback time** =  $91/34 \approx 2.7$  years [rough calc.]

*Same payback time as previous example, but different cash flows*

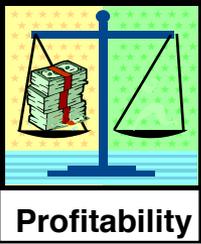
## Notes



- **No time value of money taken into account**
- Doesn't consider what happens after payback

**Not recommended!**

*Can be an effective screening tool though*



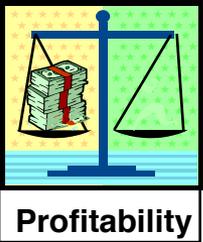
# Measures of profitability

## Return on original investment (ROI)

- Simple calculation
- $$\text{ROI} = \frac{\text{average annual profit}}{\text{fixed capital} + \text{working capital}}$$
- Expressed in units of percent per year

**What is fixed capital?  
What is working capital?**



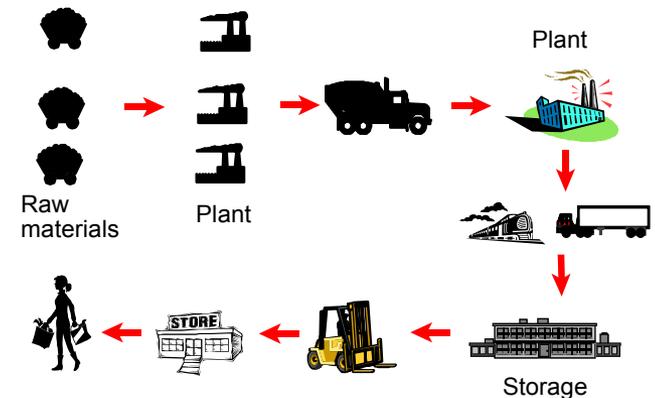


# Measures of profitability

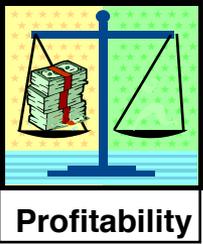
## Working Capital

**Working capital is the difference between current assets and current liabilities. (Estimation given later in course.) Examples include:**

- Raw materials
- Work in progress (WIP), which is material part way through the production
- Supplies stored for manufacturing, e.g., catalyst
- Finished products in storage and transport that we still own
- Cash on hand to cover short-term expenses



**A key feature of working capital is that it can be recovered when the plant is shutdown.**



# Measures of profitability

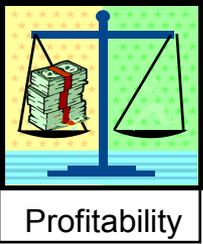
- Calculate the ROI for a project with fixed capital of \$91,000, no working capital, and an average annual profit of \$34,000.

$$\text{ROI} = 34/91 \times 100 \approx 34\%$$



**Does not consider time value of money**

**Not recommended!**



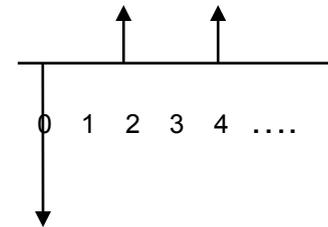
# Measures of profitability

## Net Present Value (NPV) (NP worth)

- Explicitly expressed as a **specific value of money**
- Defined as present value of all cash flows
- Sum up these present values (i.e. “net” them up)
- For  $N$  compounding periods in the life of the project, with a net cash flow in each period of  $C_n$

recommended

$$NPV = \sum_{n=0}^N C_n (1+i)^{-n}$$



What does  $NPV=\$0$  imply?



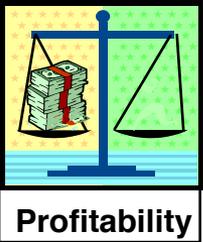
Profitability

# Measures of profitability

## Class exercise: Net Present Value (NPV)

Period	Cash Flow (\$)	PV of cash flow (\$)
0	-91,093	
1	20,000	
2	40,000	
3	40,000	
4	40,000	
5	30,000	

Calculate the **NPV** for this project at 15% time value of money



# Measures of profitability

## Class exercise: Net Present Value (NPV)

See the calculations below and *on the course website*

Payback time	Period	Cash (\$)	Present value (\$)	Cumulative sum of PV (\$)	Cumulative cash flow (\$)
	0	-\$91,093	-\$91,093	-\$91,093	-\$91,093
	1	\$20,000	\$17,391	-\$73,702	-\$71,093
Interest rate	2	\$40,000	\$30,246	-\$43,456	-\$31,093
0.15	3	\$40,000	\$26,301	-\$17,155	\$8,907
	4	\$40,000	\$22,870	\$5,715	\$48,907
	5	\$30,000	\$14,915	\$20,630	\$78,907

What does this value mean?

From prior exercise

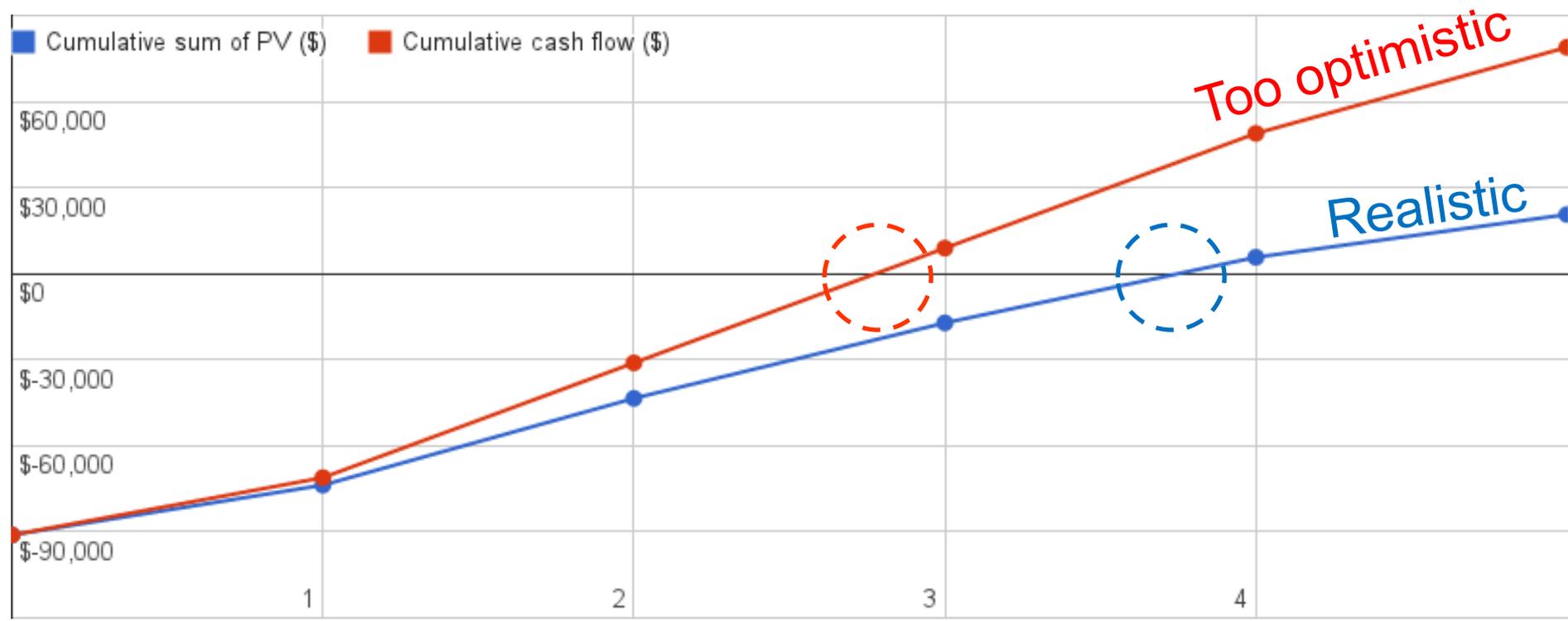
This approach considers time value of money explicitly. Important for projects of long duration, and in high deflationary environments.



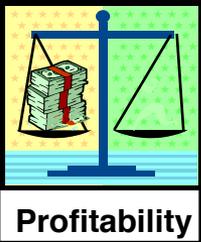
Profitability

# Measures of profitability

## Class exercise: Net Present Value (NPV)



**Payback time** **not** taking **time value of money** into account is too optimistic.

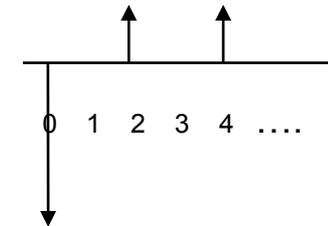


# Measures of profitability

## Discounted Cash Flow Rate Of Return (DCFRR)

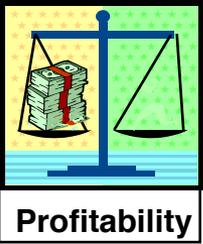
- Also called, Discounted Cash Flow (DCF)  
Internal Rate of Return (IRR)
- Defined as the interest rate that results in a NPV of \$0

$$NPV = \sum_{n=0}^N C_n (1+i)^{-n} = 0$$



recommended





# Measures of profitability

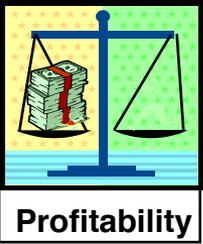
## Internal Rate of Return (IRR)

- Why *internal*? It is the NPV from this project's (internal) cash flows. NOT dependent on other project's.
- Simplest example: you invest \$100 now and wish to have \$108 next year. What is the rate of return, i.e. the IRR, required to achieve this?

Now use the equation below.

$$\text{NPV} = \sum_{n=0}^N C_n (1+i)^{-n} = 0$$

The diagram shows a horizontal timeline starting at time 0 and extending to the right. At time 0, there is a downward-pointing arrow. At time 2 and time 4, there are upward-pointing arrows. The timeline is labeled with 0, 1, 2, 3, 4, and an ellipsis (...).



# Measures of profitability

**Class exercise:** Discounted cash flow rate of return (DCFRR)

Period	Cash Flow (\$)
0	-91,093
1	20,000
2	40,000
3	40,000
4	40,000
5	30,000

Calculate the DCFRR for this project (you'll need a computer for this)



Profitability

# Measures of profitability

Calculate the **DCFRR** for this project

**DCFRR =  $i = 0.236$  or **23.6%**** (By **trial and error**, use “goal seek”)

Payback time	Period	Cash (\$)	Present value (\$)	Cumulative sum of PV (\$)
	0	-\$91,093	-\$91,093	-\$91,093
	1	\$20,000	\$16,182	-\$74,911
Interest rate	2	\$40,000	\$26,184	-\$48,727
<b>0.23597</b>	3	\$40,000	\$21,185	-\$27,542
<i>Adjust this value to get cumulative sum of PV, i.e. NPV = 0</i>	4	\$40,000	\$17,141	-\$10,401
	5	\$30,000	\$10,401	<b>\$0</b>

So the DCFRR is 23.6% in this example over the 6 periods of the project's life.

**What does this value mean?**

Considers time value of money explicitly

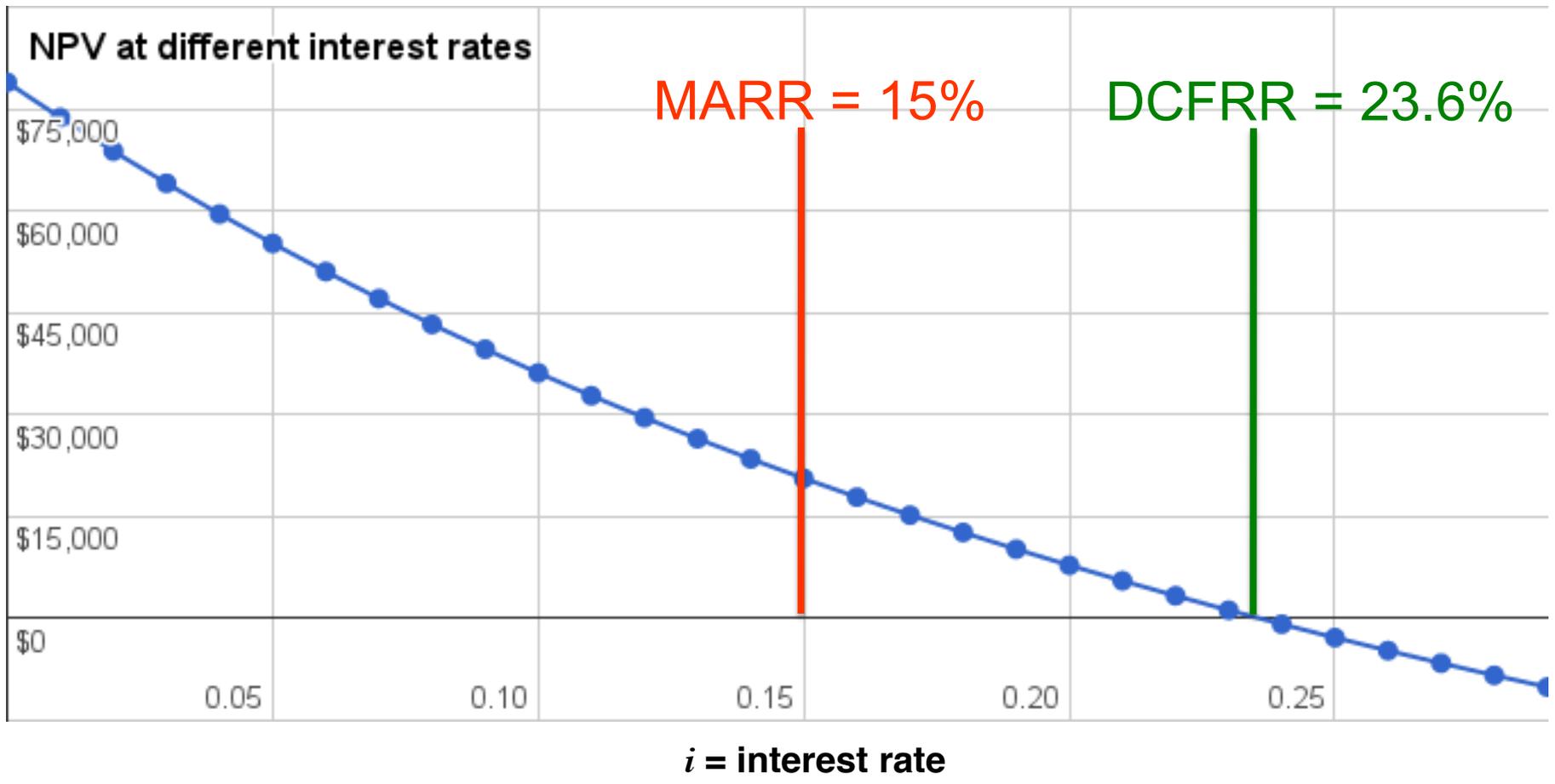


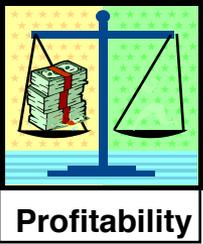
Profitability

# Measures of profitability

*This is a fixed value that the company chooses* →

A profitable investment has  $DCFRR > MARR$





# Measures of profitability

Calculate the DCFRR for the following cash flows

year	0	1	2	3
A	-1000	750	390	180
B	-1000	350	470	660
C	-1000	533	467	400

Which one is better?





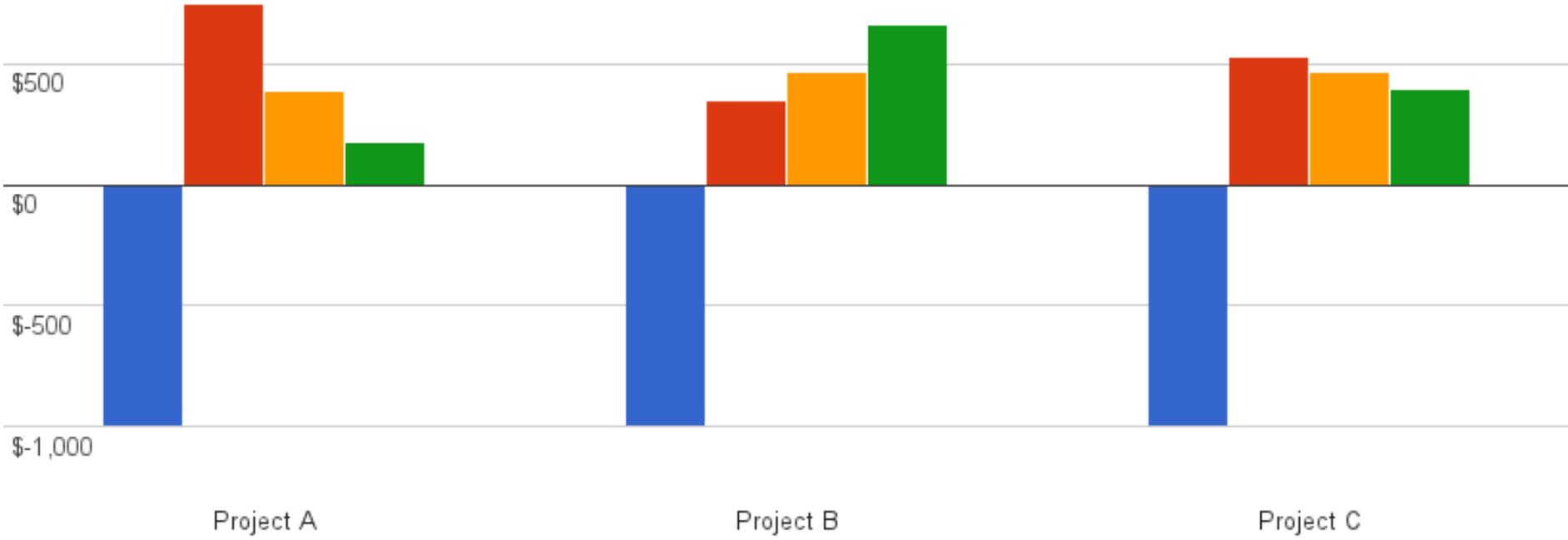
Profitability

# Measures of profitability

Calculate the DCFRR for the following cash flows

## Cash flow diagrams

Cash flows (in future value, FV) for projects A, then B, then C





Profitability

# Measures of profitability

Calculate the DCFRR for the following cash flows

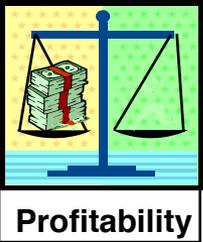
Period	Project A	Project B	Project C		Period	Cuml PV A	Cuml PV B	Cuml PV C
0	-\$1,000	-\$1,000	-\$1,000		0	-\$1,000	-\$1,000	-\$1,000
1	\$750	\$350	\$533		1	-\$375	-\$708	-\$556
2	\$390	\$470	\$467		2	-\$104	-\$382	-\$231
3	\$180	\$660	\$400		3	\$0	\$0	\$0
DCFRR	0.2000	0.2000	0.2000	<i>calculated with the =IRR(...) function</i>				

Different cash flows with the same DCFRR.

*How do we interpret this?*

Which one is better?



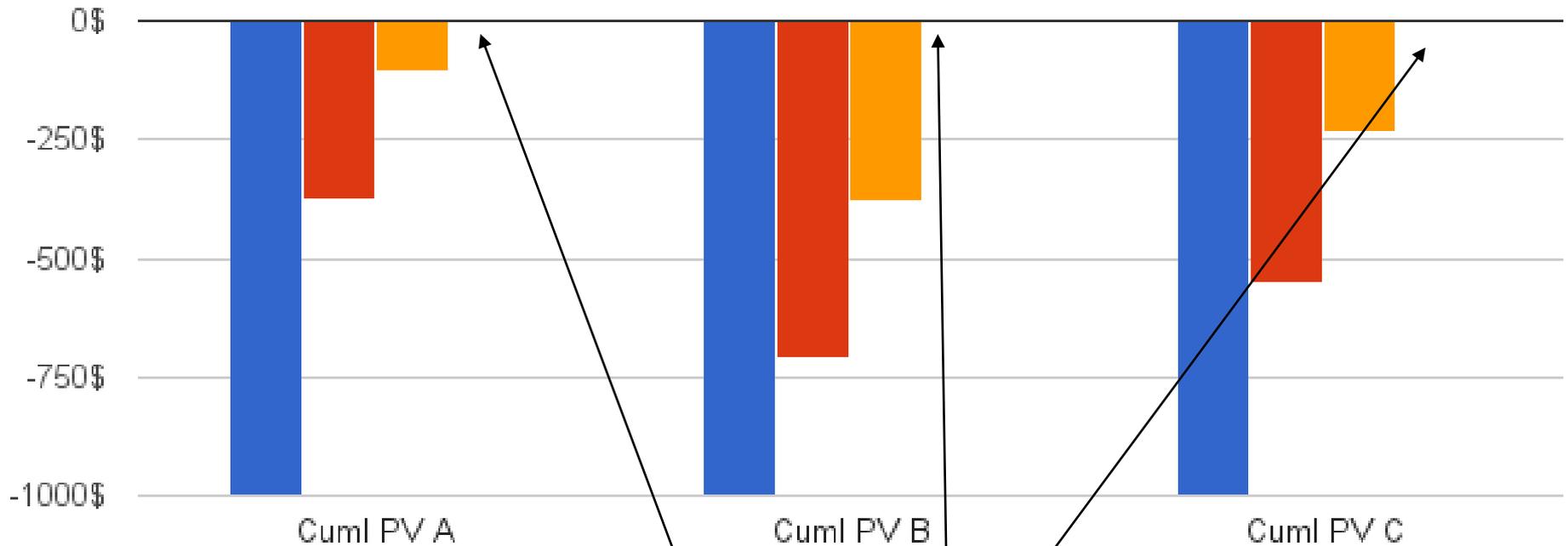


# Measures of profitability

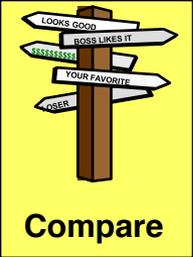
Calculate the DCFRR for the following cash flows

Cumulative NPV using  $i_{TVM}=20\%$

PV cumulative cash flows for projects A, then B, then C



*All projects reach NPV = \$0 in period n=3*

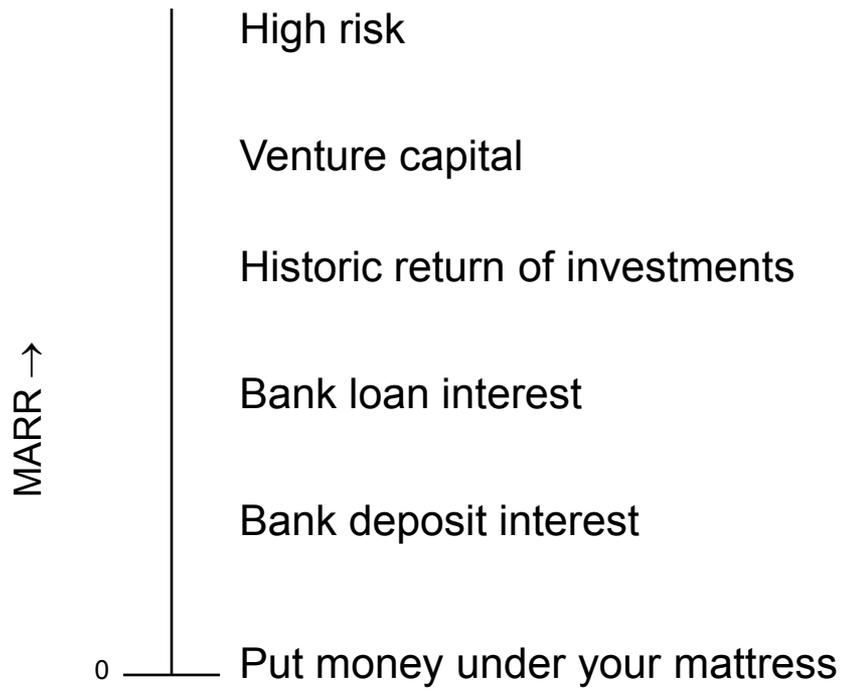
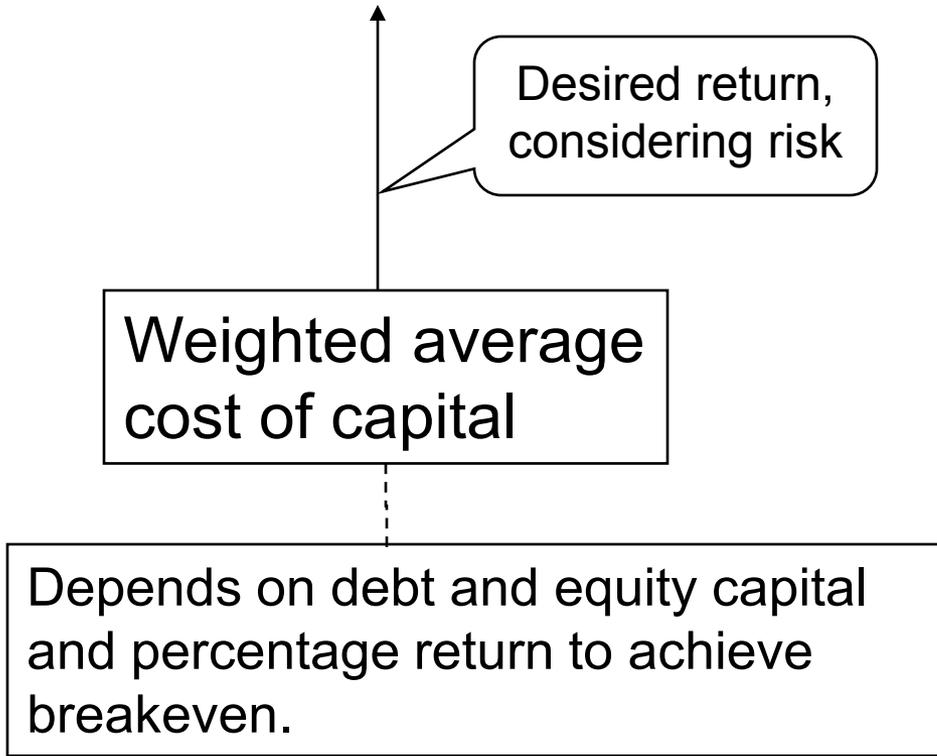


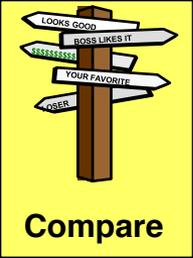
*We will come back to this topic again*

# **Detour: Comparison of alternatives**

**We will need to know the following term**

**MARR = Minimum Acceptable (compound) Rate of Return**





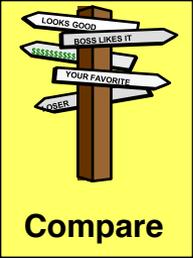
# Detour: Comparison of alternatives

MARR = Minimum Acceptable Rate of Return

Sample values from Peters *et al.* Table 8-1.\*

Description	Level of risk	Typical MARR (%)
Very low risk, hold capital short-term	Safe	4-8
New production capacity where company has established position in market	Low	8-16
New product or process technology, company has established market position	Medium	16-24
New process or product in new market	High	24-32
High R&D and marketing development	Very High	32-48

\* Descriptions modified slightly



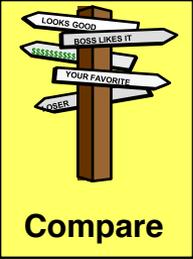
# Detour: Comparison of alternatives

The analysis depends on the scenario

- Alternatives are: “project” or “do nothing”
- **Independent** alternatives

- **Mutually exclusive** alternatives
- **Contingency dependent** alternatives

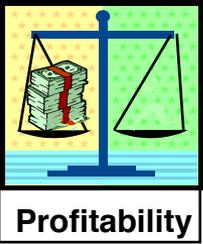
*We cover these later*



# Detour: Comparison of alternatives

Comparing one alternative with “Do nothing”

- The “do nothing” alternative in a large company implies the that the money can be invested with a return rate = **MARR**.
- We always have the (*independent*) alternative of placing the money in an interest bearing bank account. This defines a lower limit on MARR.
- Therefore, we always compare alternatives.

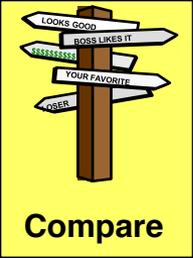


# Measures of profitability

Can you have an investment with  $DCFRR > MARR$ , but  $NPV < \$0$  (calculating NPV with  $i_{TVM} = MARR$ )?

Can you have an investment with  $DCFRR < MARR$ , but  $NPV > \$0$  (calculating NPV with  $i_{TVM} = MARR$ )?

Can you have an investment with  $DCFRR < MARR$ , and  $NPV < \$0$  (calculating NPV with  $i_{TVM} = MARR$ )?

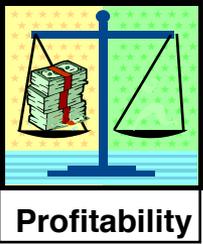


# *Detour:* Comparison of alternatives

## Independent alternatives

- Compare each alternative with the MARR
- Pick all combinations of investments for which:  
NPV > \$0 using  $i_{\text{TVM}} = \text{MARR}$   
DCFRR > MARR
- Since they are independent, sufficient funds exist for all acceptable alternatives

**Analysis for independent alternatives  
compares each project's DCFRR to the MARR**



# Measures of profitability

We have learned four measures of profitability

- **Payback time**
- **ROI**



**Not recommended!**

Unfortunately, both are used in everyday settings, so managers will often request these values. Just recognize their limitations.

- **NPV**
- **DCFRR**



**Recommended**

**Note:** both NPV and DCFRR require an estimate of  $N$  (project lifetime)

Which will you use in your course project and engineering practice?

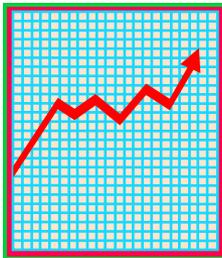


Profitability

# Measures of profitability

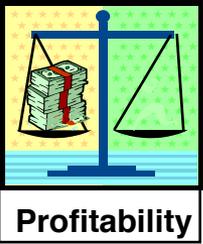
In summary, we have learned four methods

- What are they?
- Why did we learn more than one method?
- Which are recommended?
- Which will you use in your course projects?
- Which will you use in profession practice?



Is the project  
profitable or unprofitable?

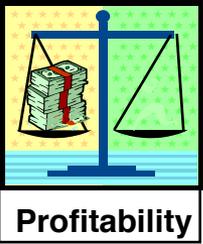




# Measures of profitability

**Self-directed learning:** Covering the topic, extending beyond these visual aids.

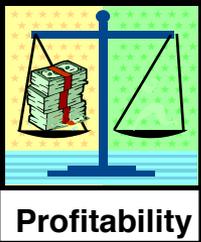
1. For all four methods determine typical threshold values that define the boundary between attractive and unattractive projects  
Find the MARR for a company/sector you are interested in.
2. Investigate a fifth method, annual worth, define its threshold value, and explain when this method is most often used.
3. Determine how inflation affects the calculations of profitability measures.
4. Describe a mathematical method that you could use to calculate the DCFRR (IRR). How could you calculate the DCFRR (IRR) with the use of an Excel spreadsheet?



# Measures of profitability

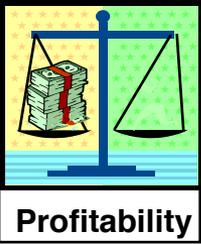
## Extending profitability coverage

Depreciation and Taxes  
must be taken into account



# Corporate taxes and depreciation

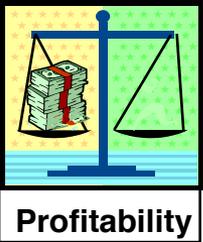
- To this point, we have considered cash flows without tax. This is called Cash Flow Before Tax (CFBT). However, companies have to pay income taxes.
- Governments and non-profit organizations do not have to pay income tax.
- Tax rates generally depend on income level, but we will consider cases with high enough income that the tax rate will be considered constant.
- We will take a tax rate of **25%** unless otherwise stated. Confirm that this is reasonable (CRA website).



# Corporate taxes and depreciation

*Drive that new car off the car agent's lot ...*

- **Depreciation** means a decrease in worth. This could be due to wear and tear, technology changes (obsolescence), depletion, inflation, or failures.
- Companies must replace capital. *The government allows companies to lower their taxes through depreciation allowances – this helps to provide resources for (re)investment.*
- Is this “fair”?
- Can you depreciate your personal car ?



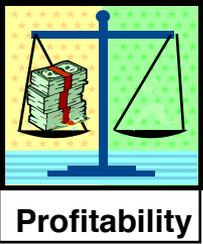
# Corporate taxes and depreciation

Capital goods that can be depreciated are defined by the government. Typical properties of goods that can be depreciated are the following:

1. It must be used for the production of income.
2. It must have a determinable life longer than 1 year.
3. It must lose value over time.

**Exercise:** Which of the following can be depreciated by Suncor?

Laptop computers; printer paper; distillation columns; pumps; employee salaries; office buildings; land for the office buildings; company travel; CEO jet/vehicle; company travel; internet connection fees.



# Corporate taxes and depreciation

- The government defines what and how goods can be depreciated (Canada Revenue Agency, CRA). We will cover the basic concepts in this course, not the detailed tax laws of **Canada or another country**.
- The company can **reduce its taxable income** by a loss in value of its equipment, i.e., by the depreciation. This reduces the taxes, not the company's actual income.

Tax paid = (tax rate) x (income – eligible expenses – depreciation)



Profitability

## Corporate taxes and depreciation

The following are “capital investments” and depreciated according to rules to be presented. **These are non-eligible expenses.** All non-eligible expenses are rolled up into the “**book value**”

- The equipment cost itself
- Improvements in equipment and processes
- Design engineering
- Equipment shipping and installation
- Land improvements\*, site preparation (roads, sewers etc.)

The following are “expensed”, i.e., the **full cost is deducted** from income in the year of the cash flow. These are “**eligible expenses**”:

- All other expenses, e.g. salaries, utilities, raw materials, consumables, *etc*

\* The value of land is never depreciated, but it is expensed.



Profitability

# Corporate taxes and depreciation

Canada Revenue Agency, CRA term for **depreciation** is

**Capital Cost Allowance (CCA)**

## **Class 8 (20%)**

Class 8 with a CCA rate of **20%** includes certain property that is not included in another class. Examples include furniture, appliances, tools costing \$500 or more per tool, some fixtures, machinery, outdoor advertising signs, refrigeration equipment, and other equipment you use in business.

## **Class 52 (100%)**

Include in Class 52 with a CCA rate of 100% (with no half year rule) general-purpose electronic data processing equipment ... if they were acquired after January 27, 2009, and before February 2011, but not including ...

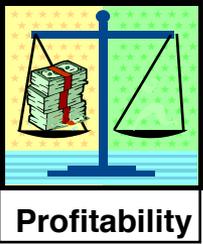
## **Class 10 (30%)**

Include in Class 10 with a CCA rate of **30%** general-purpose electronic data-processing equipment (commonly called computer hardware) and systems software for that equipment, including ancillary data-processing equipment, if you acquired them before March 23, 2004, or after March 22, 2004, and before 2005, and you made an election.

Also include in Class 10 motor vehicles as well as some passenger vehicles as defined in Type of vehicle

*etc, etc*

**Check class 43: that usually applies.**

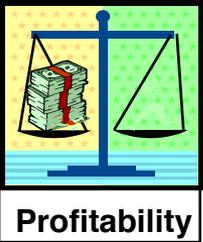


# Corporate taxes and depreciation

Depreciation in a time period is calculated as a ***percentage of the initial investment*** or remaining book value in that time period.

- Starts when equipment is “put in service”. The length of time that the depreciation will take place is defined by the government in some cases.
- The remaining value at the end of each period is termed the “book value”.
- The initial book value is the purchase (installed) price.

**includes engineering, transportation, installation, and site preparation costs. We’ll see more in “Cost Estimation”.**



# Corporate taxes and depreciation

Let's look at ONE major depreciation method only.

But first, we recall that the typical time period is one year. When in the year does the company invest, January 1 or December 31?

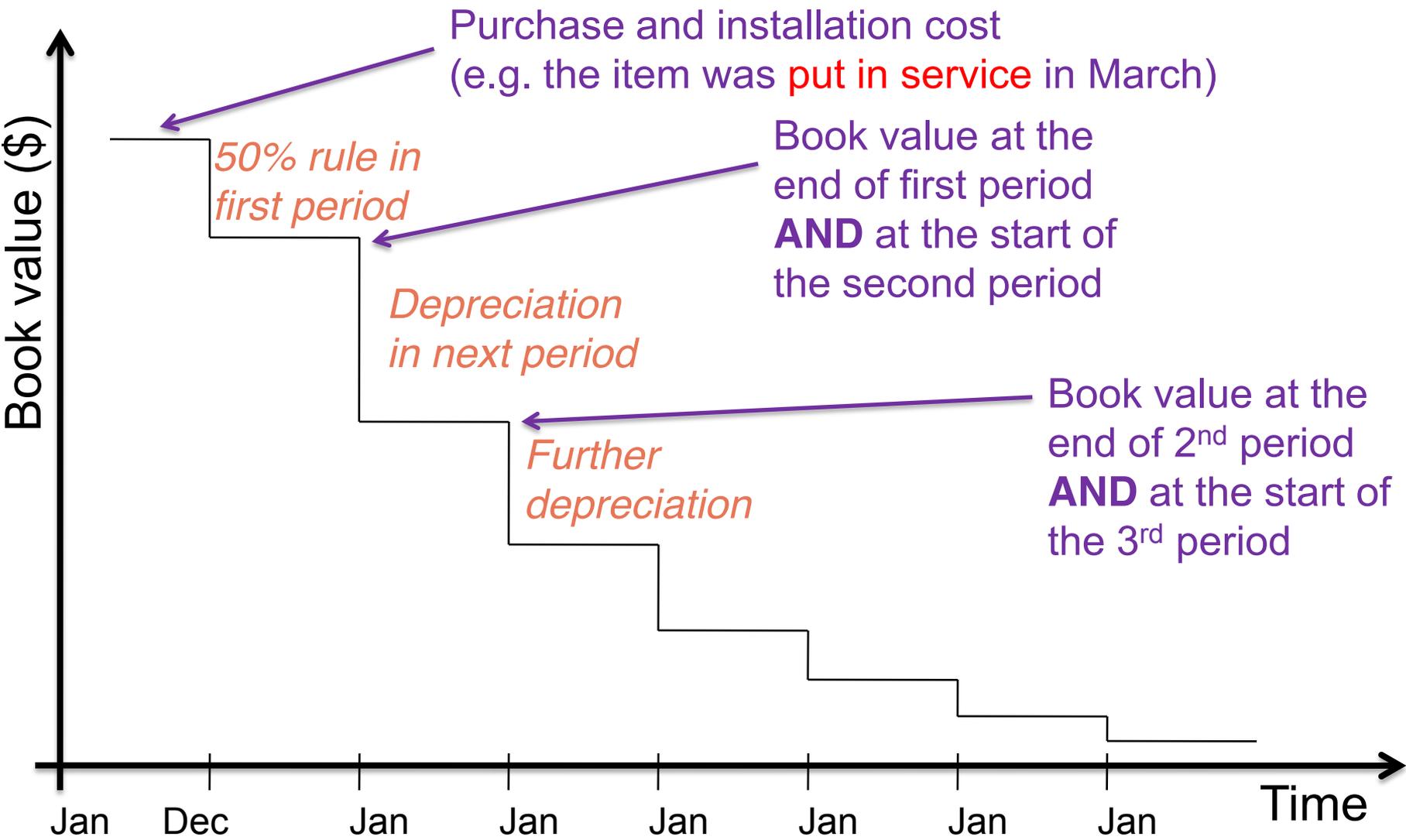
**50% Rule** : The government sets the rules. It assumes that the investment is made in the middle of the year, and it allows only 50% of the depreciation for the first year.

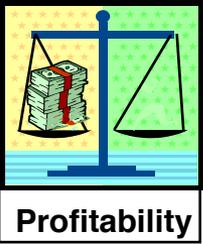
**We must abide by this rule!**



Profitability

# Corporate taxes and depreciation





# Corporate taxes and depreciation

## Declining balance depreciation

In this method, a percentage of the book value in each year is depreciated, so that the depreciated amount each year is not constant.

$$D_n = d \times B_n$$

$B_0$  = initial cost (installed price) of equipment

$B_n$  = book value at time  $t$

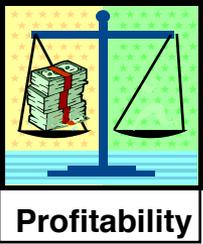
$$B_n = B_{n-1} - D_{n-1}$$

$d$  = depreciation rate (government class)

$D_n$  = **amount** depreciated each year

$$D_0^{\text{actual}} = 0.5D_0$$

*50% rule applies in first period*



# Corporate taxes and depreciation

## Example

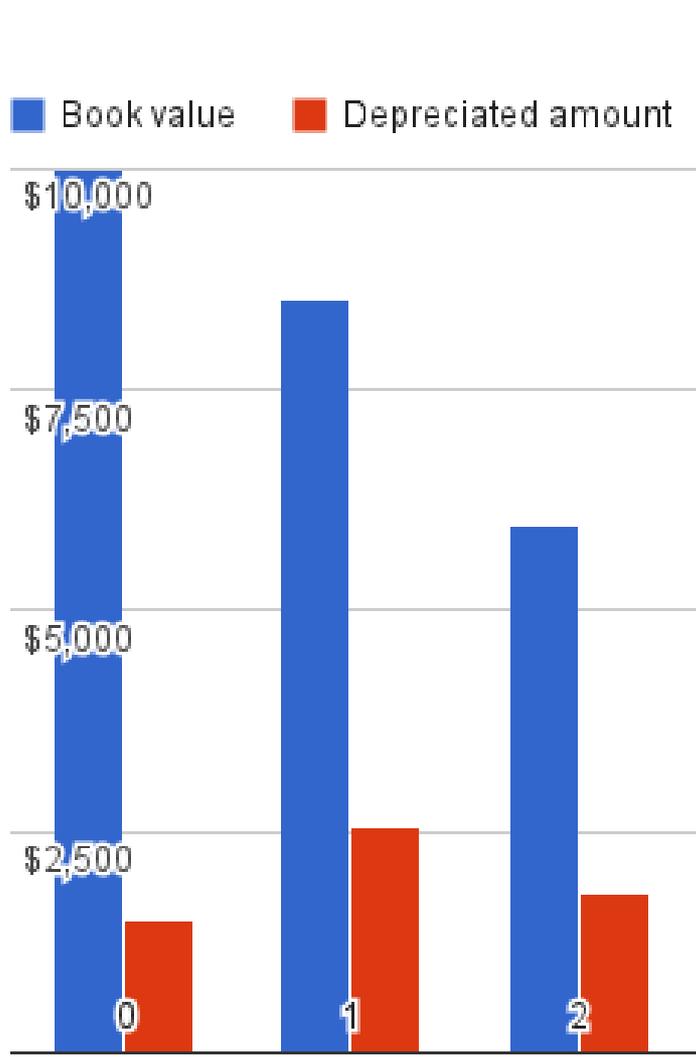
Suncor is purchasing a new reboiler for \$10,000,000. The **CRA class is 43, with a rate of 30%**. Calculate and plot the book value ( $B_n$ ) and depreciated amount ( $D_n$ ) for 8 years.

Work in rounded \$1000's.



Profitability

# Corporate taxes and depreciation



Depreciation rate = 0.3

Period	Book value	Depreciated amount
0	\$10,000	\$1,500
1	\$8,500	\$2,550
2	\$5,950	\$1,785
3	\$4,165	\$1,250
4	\$2,916	\$875
5	\$2,041	\$612
6	\$1,429	\$429
7	\$1,000	\$300



Profitability

# Corporate taxes and depreciation

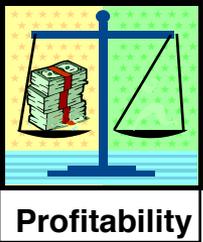
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4	\$2,916	\$875
5	\$2,041	\$612
6	\$1,429	\$429
7	\$1,000	\$300

What happens with these depreciated amounts?  
 The total will eventually add up to the original book value.

Is it an income?  
 Is it an expense?  
 Does it exist as cash in the company's bank account?

**Note:** those depreciated amounts are not deflated for TVM, so their true value is actually less in PV terms.



# Corporate taxes and depreciation

What's the main advantage of depreciation for the company?

**The company pays lower taxes!** They can *reduce* their **taxable income** in a year by the amount of **depreciation** during the year. The company can, in **each** period:

**A** = sum **all income** and revenues

**B** = sum **all eligible expenses** (use –ve's for expenses)

**C** = all non-eligible expenses (use –ve's; equipment, shipping, installation, *etc*)

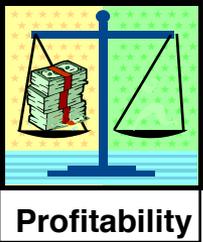
**D** = calculate the book value (at start of the period; update it from previous)

**E** = calculate the depreciation, and **sum all depreciations up** [always +ve]

**F** = **taxable income** = **A** + **B** *minus E* (note that **B** must have negative sign)

**G** = **tax paid** = (**taxable income**) \* (tax rate) [can be a +ve or –ve result]

**H** = net cash flow for period = **A** + **B** + **C** *minus G*; then adjust **H** for TVM

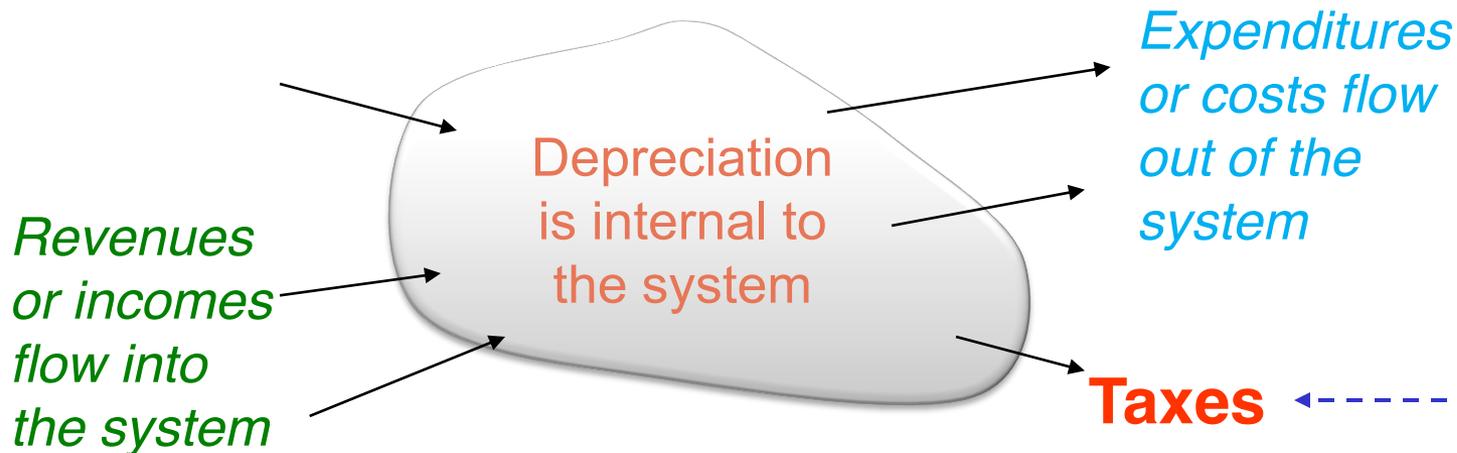


# Corporate taxes and depreciation

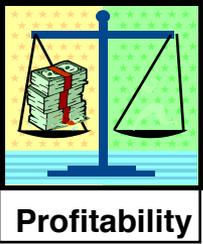
Point of frequent misunderstanding:

***Depreciation is not a cash flow!***

However, it affects one cash flow: **tax payments!**



# Corporate taxes and depreciation



Evaluate the **profitability** for installing an automated, online pulp quality analyzer (Kappa number) on a Kraft digester.

Analyzer capital cost including installation = \$75,000

Analyzer maintenance cost = \$5,000/year (except for first year)

Increased profit due to improved pulp quality = \$20,000/year

Depreciate the analyzer using the declining balance method. The analyzer has an expected life of 5 years. The salvage value is \$0.

Assume it is January 2014. Your company's year end is 31 December.

Assume the equipment can be installed and put in service in January 2014.

Calculate the **payback time**, **cash flows** in each period, **NPV** (using a TVM of 8%), and **DCFRR**. The company's MARR is 10%.

In class: set up the problem and calculate for  $n=0$ ,  $n=1$ . Do the rest at home.



# Corporate taxes and depreciation

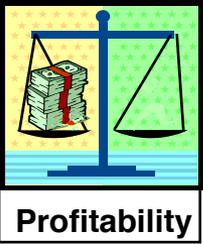
Profitability

Depreciation rate = **0.3**  
 TVM rate = **0.08**  
 Corporate tax rate **0.25**

Period	Revenue [A]	Eligible Exp [B]	Non-eligible exp [C]	Book value [D]	Depreciation [E]	Taxable income [F]
0	\$20,000	\$0	-\$75,000	\$75,000	\$11,250	\$8,750
1	\$20,000	-\$5,000	\$0	\$63,750	\$19,125	-\$4,125
2	\$20,000	-\$5,000	\$0	\$44,625	\$13,388	\$1,613
3	\$20,000	-\$5,000	\$0	\$31,238	\$9,371	\$5,629
4	\$20,000	-\$5,000	\$0	\$21,866	\$6,560	\$8,440

Period	Tax paid [G]	Net cash flow [H]	Cumulative CF	TVM cash flow	Cuml TVM cash
0	\$2,188	-\$57,188	-\$57,188	-\$57,188	-\$57,188
1	-\$1,031	\$16,031	-\$41,156	\$14,844	-\$42,344
2	\$403	\$14,597	-\$26,559	\$12,514	-\$29,829
3	\$1,407	\$13,593	-\$12,967	\$10,790	-\$19,039
4	\$2,110	\$12,890	-\$77	\$9,475	-\$9,564
			SUM	-\$9,564	
			DCFRR	0.00	
			i.e.	0%	

Payback time is in period  $n=5$  (around 5.1 years, although the life of the equipment is 5 years, we may never reach payback). Cash flows are shown above; NPV's are as shown; DCFRR=0% *in the 5 year period.*



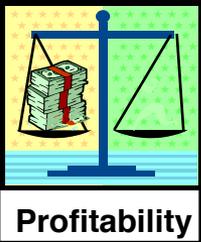
# Corporate taxes and depreciation

## Straight line depreciation

The CRA allows straight line depreciation in certain classes.

**Example:** \$10,000 over a 4 year (CRA specifies this) period, allows for

- \$2,500/2 in year 1 (BV = \$8,750)
- \$2,500 in year 2 (BV = \$6,250)
- \$2,500 in year 3 (BV = \$3,750)
- \$2,500 in year 4 (BV = \$1,250)
- \$1,250 in year 5 (BV = \$0)

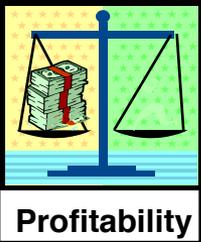


# Corporate taxes and depreciation

## Group learning / Self-learning:

1. Determine the typical corporate tax rate in several countries.
2. What is the effect on cash flow after tax when a depreciated good is sold for a price different from its book value?
3. What is the (approximate) relationship between the MARR before and after taxes?
4. The company purchases and installs new equipment on January. How much can be depreciated during the first year?

More generally, when can a company begin depreciating a capital expense?



# Corporate taxes and depreciation

## Group learning / Self-learning:

5. What is more beneficial to a profitable company? Why?
  - a. Rapid depreciation
  - b. Slow depreciation
6. How can a government encourage investment in a specific technology via the tax laws? (for example, information technology, sustainability, or environmental protection)
7. What is the effect of a negative income taxes, which can occur when depreciation is greater in magnitude than net income?

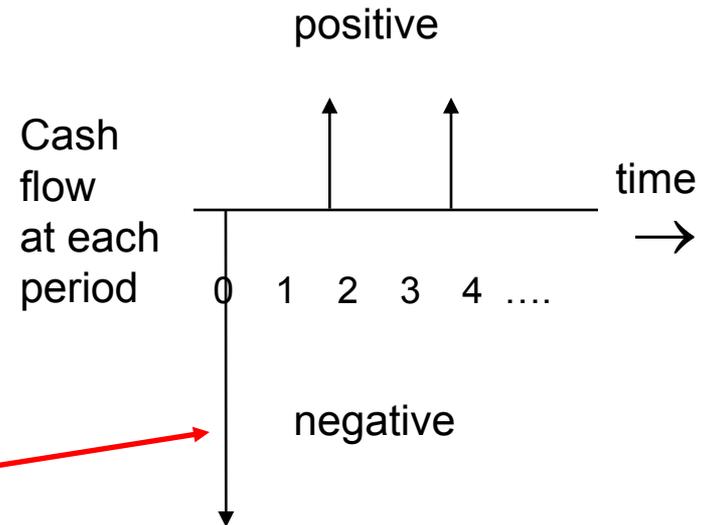


# Cost estimation

1. Time value of money
2. Quantitative measures of profitability
3. Systematic comparison of alternatives
4. Estimation of costs



We know how to calculate profitability; now, let's learn how to estimate the data, i.e., **the costs**.





# Cost estimation

Cost estimating is important to study.

## What is Syncrude?

- A. A company in Alberta, Canada.
- B. The result of heavy oil being processed to form a synthetic crude oil of further processing.
- C. A major source of crude oil for western Canada
- D. The major employer in Fort McMurray, Alberta



# Cost estimation

Syncrude has reported several changes to the cost estimate for its major expansion project that added 100,000 B/d of synthetic crude capacity.

Initial estimate: 3.6 Billion \$

First correction: 4.6 Billion \$

Second correction: 5.1 Billion \$

**“As built” cost: 8.4 Billion \$**





# Cost estimation

## Suncor is another major oil-sands company

“Suncor Energy Inc. cancelled its \$11.6-billion Voyageur upgrader project because of soaring capital costs – and the belief that better profits are to be found in shipping out unprocessed bitumen.

- Suncor will take a \$140-million writedown that will erode its first-quarter profit
- In February, Suncor wrote off \$1.5-billion of its investment in the upgrader.

Since 2010, market conditions have changed significantly, challenging the economics of the Voyageur upgrader project.

Suncor **has already invested \$3.5-billion in Voyageur**, but decided to pull the plug after a detailed review... This decision is in line with our commitment to capital discipline and our stated plan **to allocate capital with priority given to developing higher-return growth projects.**”

*Consider the ripple effect across the industry this caused*



# Cost estimation

We can always get someone else to tell us the costs.

Is this a good idea?

## Class discussion

**Equipment suppliers and technology licensors will give us estimates. We could call them and receive an estimate. This approach would involve little effort,**

**So, why is cost estimation a skill needed by all engineers?**



# Cost estimation

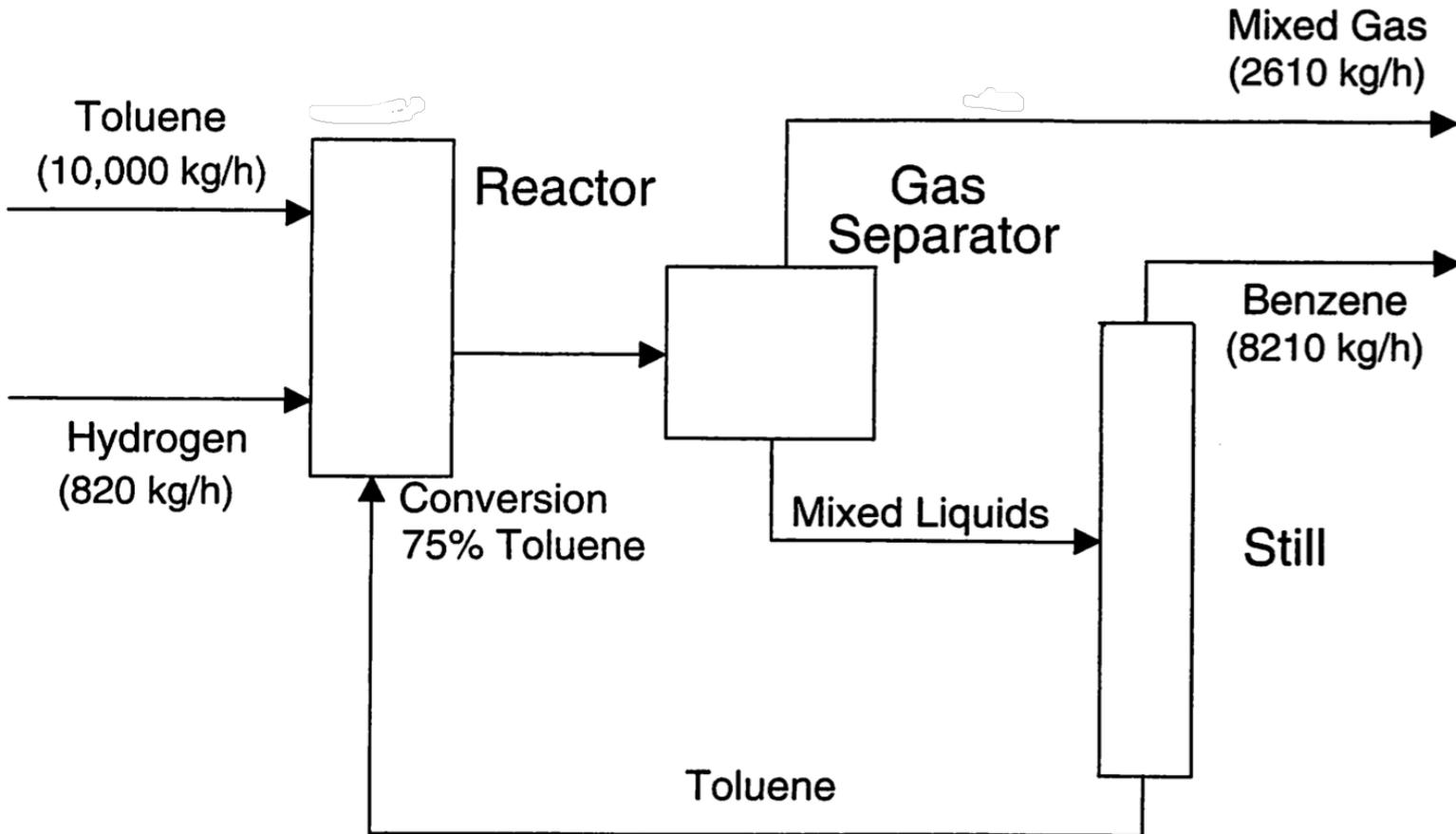
## Class question

- **Timeliness** - We need to screen many alternatives quickly
- **Judgment** - We need to evaluate the bids from equipment suppliers and technology licensors
- **Confidentiality** - We could be evaluating projects that are of interest to competitors
- **Ethics** - We should not mislead suppliers to think that we intend to purchase from them, just to have them perform our job
- **Total cost** - Project cost is much greater than equipment cost
- Other reasons perhaps?



# Cost estimation

Order of magnitude for toluene + hydrogen  $\rightarrow$  benzene

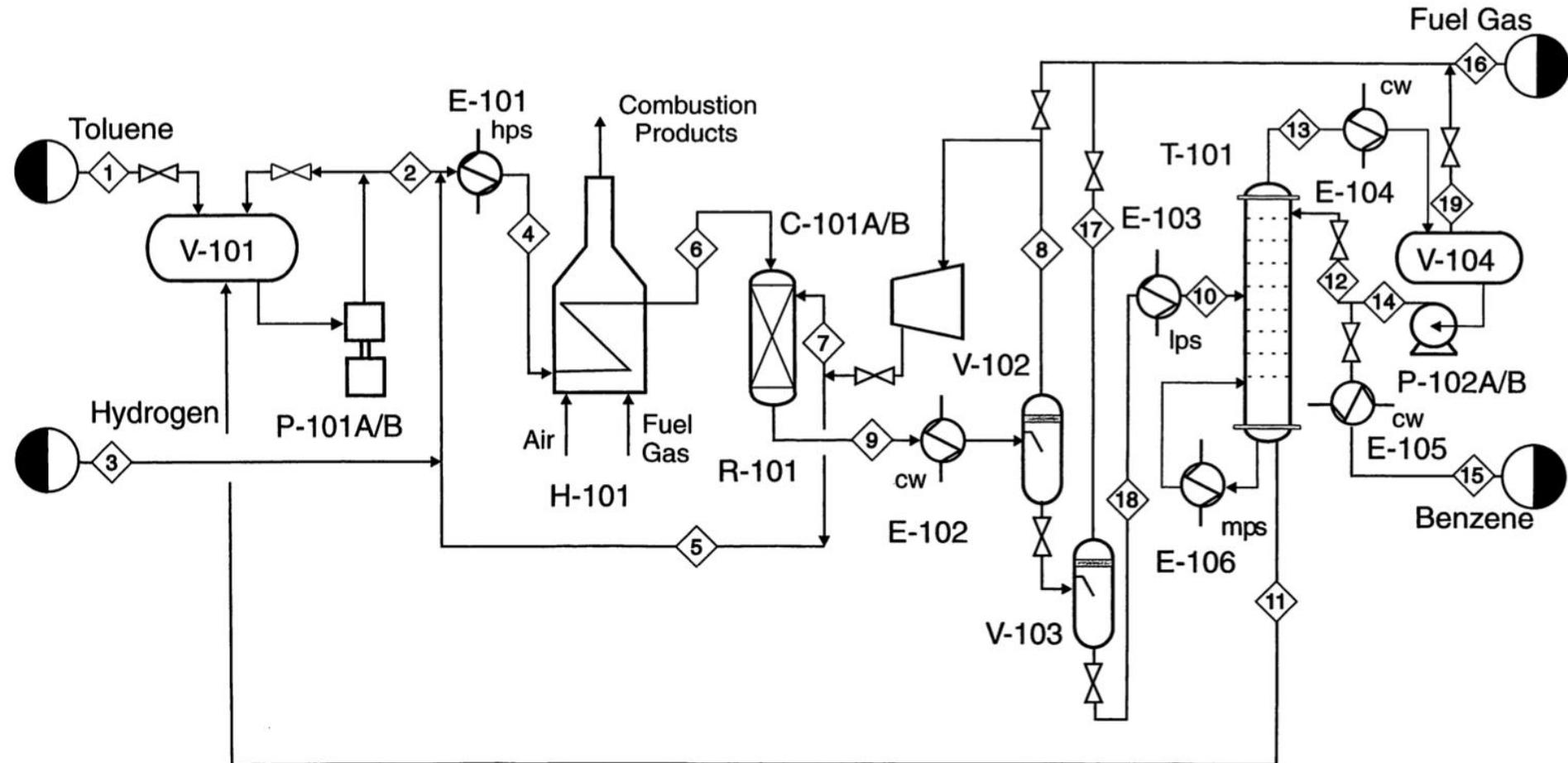


*Block flow process diagram*



# Cost estimation

Order of magnitude: heading to more detailed



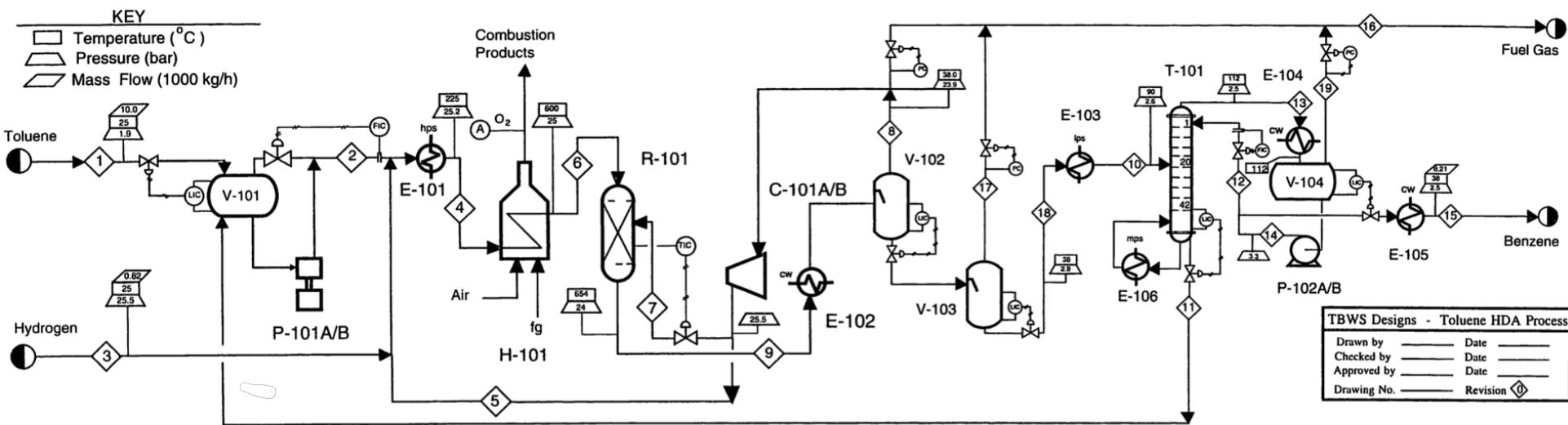
*Skeleton Process Flow Diagram*



# Cost estimation

More detailed estimate (study phase)

- V-101  
Toluene  
Feed Drum
- P-101A/B  
Toluene  
Feed Pumps
- E-101  
Feed  
Preheater
- H-101  
Heater
- R-101  
Reactor
- C-101A/B  
Recycle Gas  
Compressor
- E-102  
Reactor Effluent  
Cooler
- V-102  
High-Pres.  
Phase Sep.
- V-103  
Low-Pres.  
Phase Sep.
- E-103  
Feed  
Preheater
- E-106  
Benzene  
Reboiler
- T-101  
Benzene  
Column
- E-104  
Benzene  
Condenser
- V-104  
Reflux  
Drum
- P-102A/B  
Reflux Pump
- E-105  
Product  
Cooler

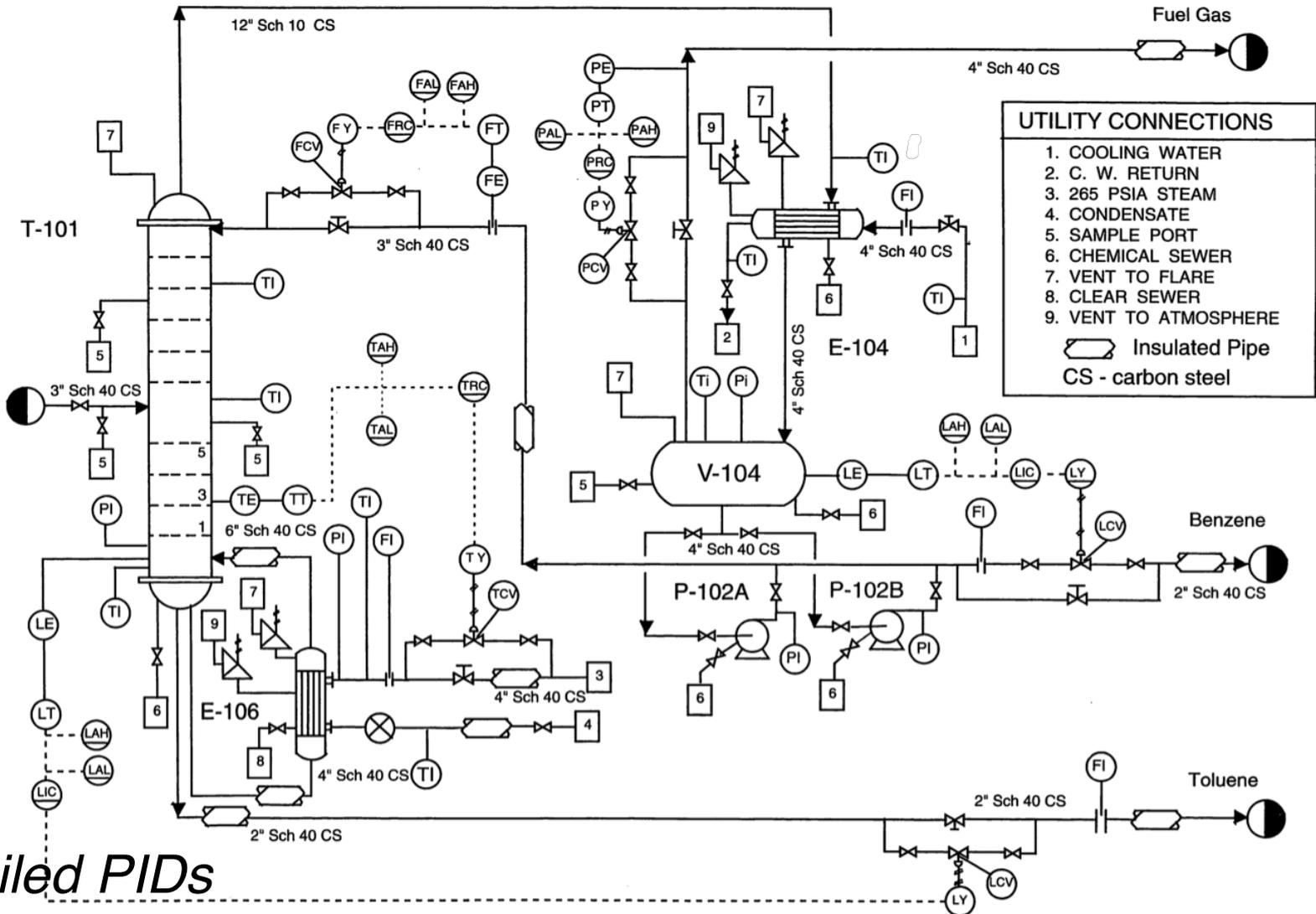


*Detailed Process Flow Diagram*



# Cost estimation

## Definitive estimates



Detailed PIDs



# Cost estimation

We must balance the needed accuracy with the cost to perform.

(See Peters and Timmerhaus, Pg 160-162)

Name	Accuracy	Application	Process detail
Order of magnitude	-30 to +50%	Screen investments	Block flow diagram
Study	-15 to +30%	Finalize major choices	PFD + rough design of major equipment
Definitive	-5 to +15%	Control costs	P&I Drawing, detailed M&E balances, equipment specifications



**Takes time and effort:** Total cost to prepare an estimate could be several \$100k, but the same effort would be required later in the design phase, part of cost is really just **pre-investment**.



# Cost estimation

We must balance the needed accuracy with the cost to perform.

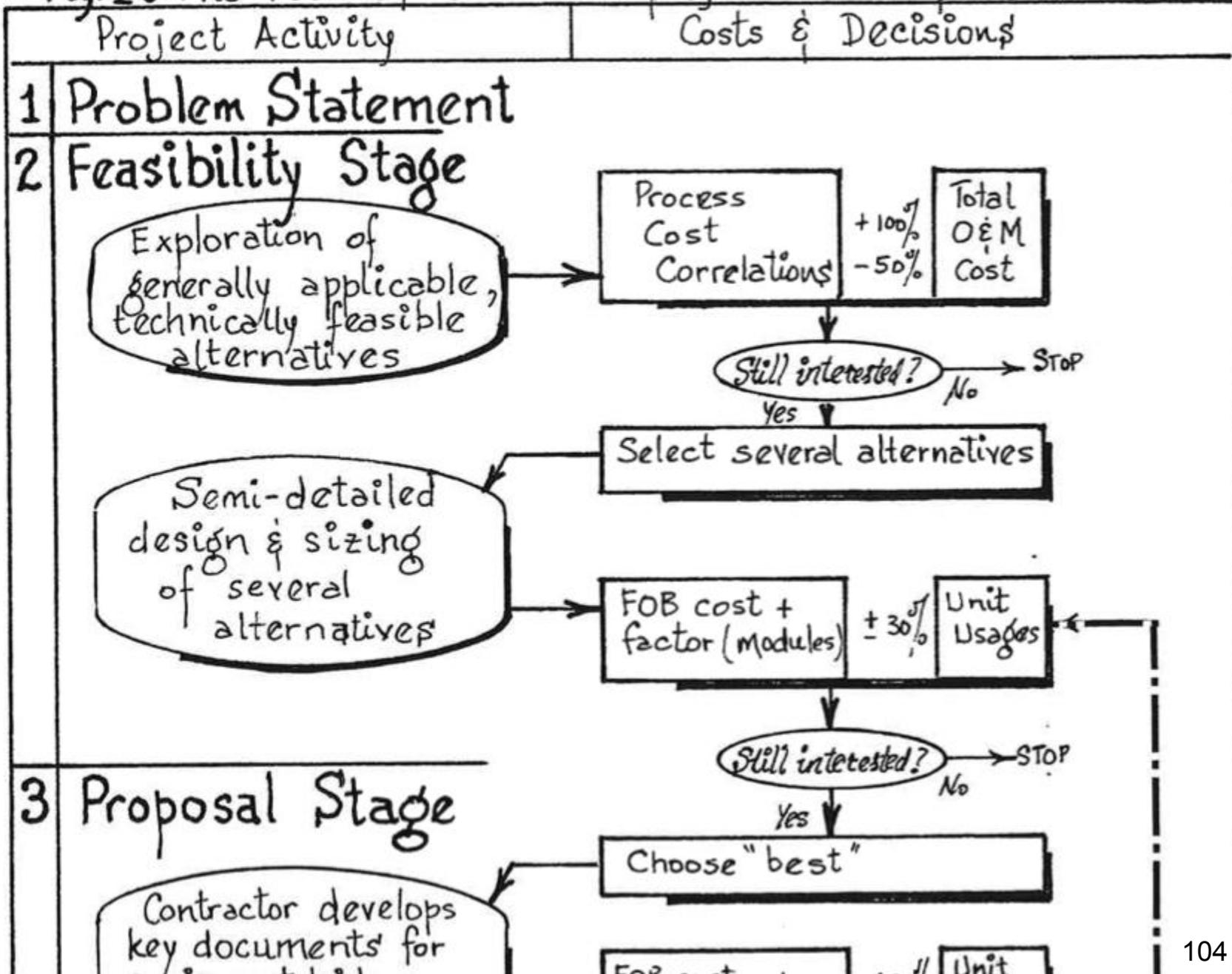
(See Peters and Timmerhaus, Pg 160-162)

Name	Accuracy	Application	Process detail
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Definitive	-5 to +15%	Control costs	P&I Drawing, detailed M&E balances, equipment specifications

**No shortcut:** A flow sheet simulation (e.g., HYSIS/PRO II/ASPEN) is required when developing a definitive cost estimation. The information is required for accurate estimates of both capital and manufacturing costs.

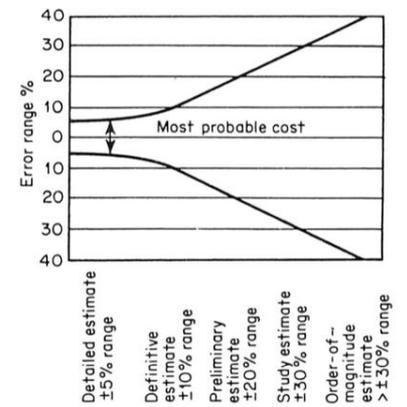


Fig. 16: The role of costs in <sup>1-21</sup> project development





# Cost estimation



This useful table is available in Peters and Timmerhaus [Fig 6.4] and in Perry's Handbook [link on course website]

It gives a summary of the type of information needed for each level of estimate.

		Required information				
		Detailed estimate ±1.5% range	Definitive estimate ±10% range	Preliminary estimate ±20% range	Study estimate ±30% range	Order-of-magnitude estimate > ±30% range
Site	Location	•	•	•	•	•
	General description	•	•	•	•	•
	Soil bearing	•	•	•	•	•
	Location & dimensions R.R., roads, impounds, fences	•	•	•	•	•
	Well-developed site plot plan & topographical map	•	•	•	•	•
	Well-developed site facilities	•	•	•	•	•
Process flow sheet	Rough sketches	•	•	•	•	•
	Preliminary Engineered	•	•	•	•	•
Equipment list	Preliminary sizing & material specifications	•	•	•	•	•
	Engineered specifications	•	•	•	•	•
	Vessel sheets	•	•	•	•	•
	General arrangement (a) Preliminary (b) Engineered	•	•	•	•	•
Building and structures	Approximate sizes & type of construction	•	•	•	•	•
	Foundation sketches	•	•	•	•	•
	Architectural & construction	•	•	•	•	•
	Preliminary structural design	•	•	•	•	•
	General arrangements & elevations	•	•	•	•	•
Utility requirements	Detailed drawings	•	•	•	•	•
	Rough quantities (steam, water, electricity, etc.)	•	•	•	•	•
	Preliminary heat balance	•	•	•	•	•
	Preliminary flow sheets	•	•	•	•	•
	Engineered heat balance	•	•	•	•	•
Piping	Engineered flow sheets	•	•	•	•	•
	Well-developed drawings	•	•	•	•	•
	Preliminary flow sheet & specifications	•	•	•	•	•
Insulation	Engineered flow sheet	•	•	•	•	•
	Piping layouts & schedules	•	•	•	•	•
	Rough specifications	•	•	•	•	•
	Preliminary list of equipment & piping to be insulated	•	•	•	•	•
Instrumentation	Insulation specifications & schedules	•	•	•	•	•
	Well-developed drawings or specifications	•	•	•	•	•
	Preliminary instrument list	•	•	•	•	•
	Engineered list & flow sheet	•	•	•	•	•
Electrical	Well-developed drawings	•	•	•	•	•
	Preliminary motor list - approximate sizes	•	•	•	•	•
	Engineered list & sizes	•	•	•	•	•
	Substations, number & sizes, specifications	•	•	•	•	•
	Distribution specifications	•	•	•	•	•
	Preliminary lighting specifications	•	•	•	•	•
Man-hours	Preliminary interlock, control, & instrument wiring specs.	•	•	•	•	•
	Engineered single-line diagrams (power & light)	•	•	•	•	•
	Well-developed drawings	•	•	•	•	•
	Engineering & drafting	•	•	•	•	•
Project scope standard processes	Labor by craft	•	•	•	•	•
	Supervision	•	•	•	•	•
Project scope standard processes	Product, capacity, location & site requirements.	•	•	•	•	•
	Utility & service requirements. Building & auxiliary requirements. Raw materials & finished product handling & storage requirements	•	•	•	•	•



# Cost estimation

## Capital costs

- Fixed equipment
- Working capital

## Manufacturing costs

- **Direct** (materials and labour that scale in proportion to throughput)
- **Fixed costs** (utilities, labour, *etc*, that are required no matter what the production rate is)

Evaluating **capital equipment cost** estimates:

Use historical data to develop correlations, and apply corrections for unique factors in specific situations.

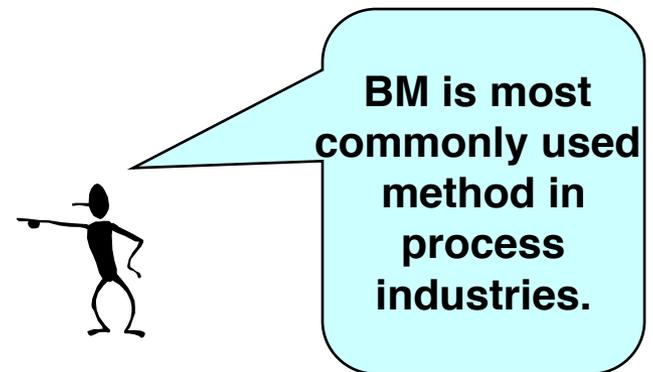


# Cost estimation

## Capital cost estimation

Methods covered in this course

- A couple of very rough methods (initial screening)
  - Turnover ratio
  - Lang's Factor
- Bare Module (BM) method
  - Concept and items included
  - Factor tables with corrections
  - Inflation
  - Examples





# Cost estimation

Very rough capital cost estimation (*use with caution!*)

**Turnover ratio:** values of 0.2 to 4.0;  
usually 0.5 in the process industries

$$(\text{Fixed capital cost})(\text{TR}) = \text{gross annual sales}$$

errors are between  $-50\%$  to  $+100\%$

We can use this to estimate the **fixed capital costs** for a plant making a known **quantity for sales**. The *number of times we turn around* our capital cost into sales.



# Cost estimation

*Please fix this*

Very rough capital cost estimation (*use with caution!*)

Lang's factor is used to estimate **fixed capital cost** given the **delivered cost** of the equipment:

$(\Sigma \text{ delivered cost of major equipment }) (\text{LF}) = \text{Fixed capital cost}$

Type of plant	Fixed capital
solids processing (cement)	4.0
solid/fluids processing (alumina)	4.3
fluids processing	5.0

1. Uses only delivered cost (no L+M for installation)
2. Estimated **fixed capital cost** includes land plus contractors fees



# Cost estimation

Delivered cost





# Cost estimation

Fixed capital cost





# Cost estimation

**Bare module method** most commonly used for capital cost estimation. Here's the general approach:

1. Historical cost for equipment (common material, low pressure, ambient temperature)
  - + correct for capacity, material, P, T, and inflation
2. FOB (free on board)
  - + labour and materials for installation
  - + shipping
3. Bare module cost
  - + contractors fees, contingencies, etc.
4. Total module cost

# Cost estimation

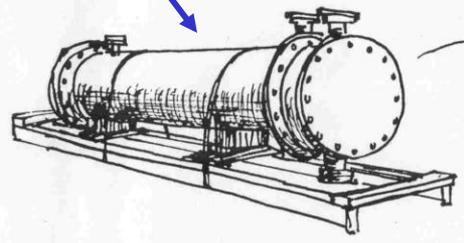
Bare module is all associated equipment and installation labour for a radius ~3m.

Reference: Woods, 1993

An illustration of the relationship between an FOB supplier situation & the Bare Module unit.

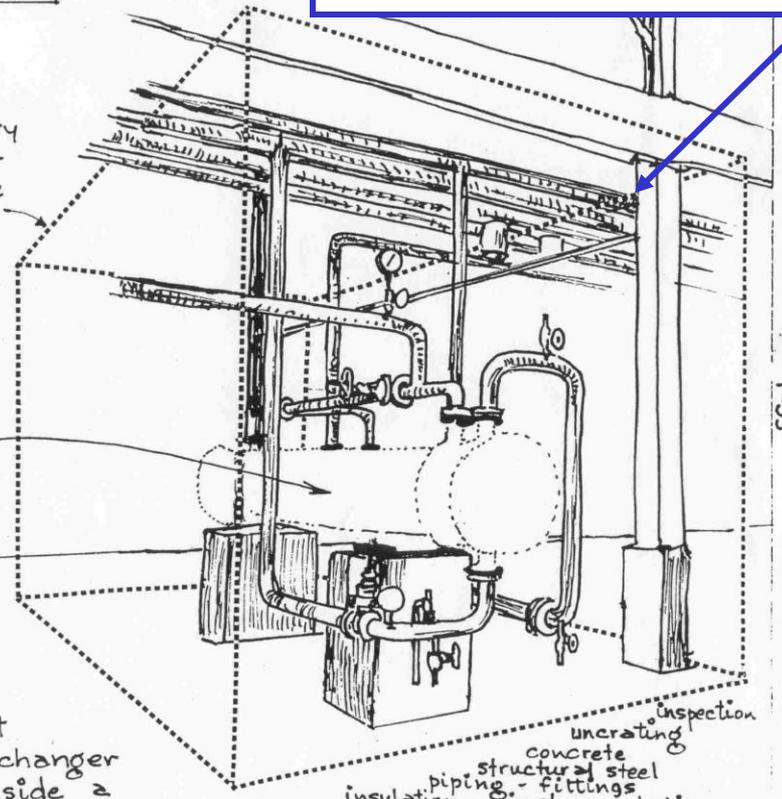
FIG 1-20

FOB cost



Heat Exchanger  
FOB supplier

Imaginary Box for Module Boundary



Heat Exchanger inside a Bare Module

inspection  
uncrating  
concrete  
structural steel  
fitting  
insulation, piping, instrumentation  
Labour.  
Field expense + Engineering overheads.



# Cost estimation

Bare module cost includes the following:

- labour and materials
- Uncrating
- Inspection
- Structure (foundation, etc.)
- Piping
- Instrumentation
- Painting and insulation
- Utility hookup (electrical, water, steam, sewer, etc.)
- Engineering supervision



# Cost estimation

## Summary of the Bare Module method

<b>FOB</b>	free on board, cost of equipment ready for shipment from supplier
<b>Installed</b> = FOB + shipping + uncrate, inspect, and hook up	
<b>L+M</b> = (installed-shipping) + piping + instruments + electrical + insulation + foundation + structure + offsites	$L+M = FOB * (L+M \text{ Factor})$
Physical plant cost = L+M + shipping	Note that shipping cannot be correlated
<b>BM</b> = above + home engineering + field expense	<p>BM = Bare module</p> <p>Home off = 9% of L+M</p> <p>Field = 10 to 15% L+M</p> <p>BM = FOB*(BM Factor)</p> <p>Rough estimate</p> <p>BM factor = <math>(L+M)*1.4</math></p>
<b>TM</b> = Total fixed capital investment = BM + contractors fees + contingencies	<p>TM = total module</p> <p>Contr = 3 to 5% of BM</p> <p>Conting = 10 to 15% of BM</p>
<b>Total investment</b> = above + royalty + land + spare parts + legal + working capital + interest during construction	<p>Working capital = 10+% of fixed capital invest.</p> <p>This could vary greatly.</p> <p>Note: This is for isolated module, not grassroots plant.</p>
<b>Turnkey cost</b> = total invest + Startup expenses	

**Notes:** 1. Total module (TM) does not account for site development, off-sites, utilities, etc. These costs would vary depending upon the equipment considered. Turton (pg. 68) suggests 35% of BM costs for this factor.



# Cost estimation

## Method and Data for Bare Module method

We have data from the past on a limited number of designs

The labour and materials depends on the equipment design

<b>FOB</b>	free on board, cost of equipment ready for shipment from supplier
<b>Installed</b> = FOB + shipping + uncrate, inspect, and hook up	
<b>L+M</b> = (installed-shipping) + piping + instruments + electrical + insulation + foundation + structure + offsites	$L+M = FOB * (L+M \text{ Factor})$
Physical plant cost = L+M + shipping	Note that shipping cannot be correlated
<b>BM</b> = above + home engineering + field expense	BM = Bare module Home off = 9% of L+M Field = 10 to 15% L+M $BM = FOB * (BM \text{ Factor})$ Rough estimate $BM \text{ factor} = (L+M) * 1.4$
<b>TM</b> = Total fixed capital investment = BM + contractors fees + contingencies	TM = total module Contr = 3 to 5% of BM Conting = 10 to 15% of BM
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**Notes:** 1. Total module (TM) does not account for site development, off-sites, utilities, etc. These costs would vary depending upon the equipment considered. Turton (pg. 68) suggests 35% of BM costs for this factor.



# Cost estimation

## Method and data for Bare Module method

We will now cover the various “factors” that are used to enable us to estimate the cost of equipment with various capacities, pressures, etc. from a limited set of data.

Limited number of specific equipment designs and times

Correction for the “capacity”

Correction for the inflation from the database year

$$\text{BM cost} = [\text{Database}] \times [\text{capacity factor}] \times [\text{inflation factor}] \times [\text{installation factor}] \times [\text{operating condition correction}]$$

Additional cost for equipment and labour to connect to the process

Correction for process conditions that affect the capital cost, e.g., pressure, and for materials of construction



# Cost estimation

**Capacity factor** - Converting the historical capital cost data to FOB using the power law.

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[ \frac{\text{Factor}_A}{\text{Factor}_B} \right]^n$$

1. What is a typical value for “n”?
2. Why does a power-law work?

Usually set **B = known** and **A = new design**

The “factor” is selected to be the feature of the design that correlates best with the **capital cost** item.





# Cost estimation

**Capacity factor** - Converting the historical capital cost data to FOB using the power law.

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[ \frac{\text{Factor}_A}{\text{Factor}_B} \right]^n$$

What is the correct **factor** for a shell and tube heat exchanger?

- Heat duty
- area
- number of tubes
- flow rate

What is the **exponent** for a shell and tube heat exchanger?





# Cost estimation

**Capacity factor** - Converting the historical capital cost data to FOB using the power law.

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[ \frac{\text{Factor}_A}{\text{Factor}_B} \right]^n$$

Area has the dominant effect on manufacturing cost.

Pumps:  $\text{m}^3/\text{s}$  or power  
Agitators: power  
Distillation: height\*diameter

What is the correct **factor** for a shell and tube heat exchanger?

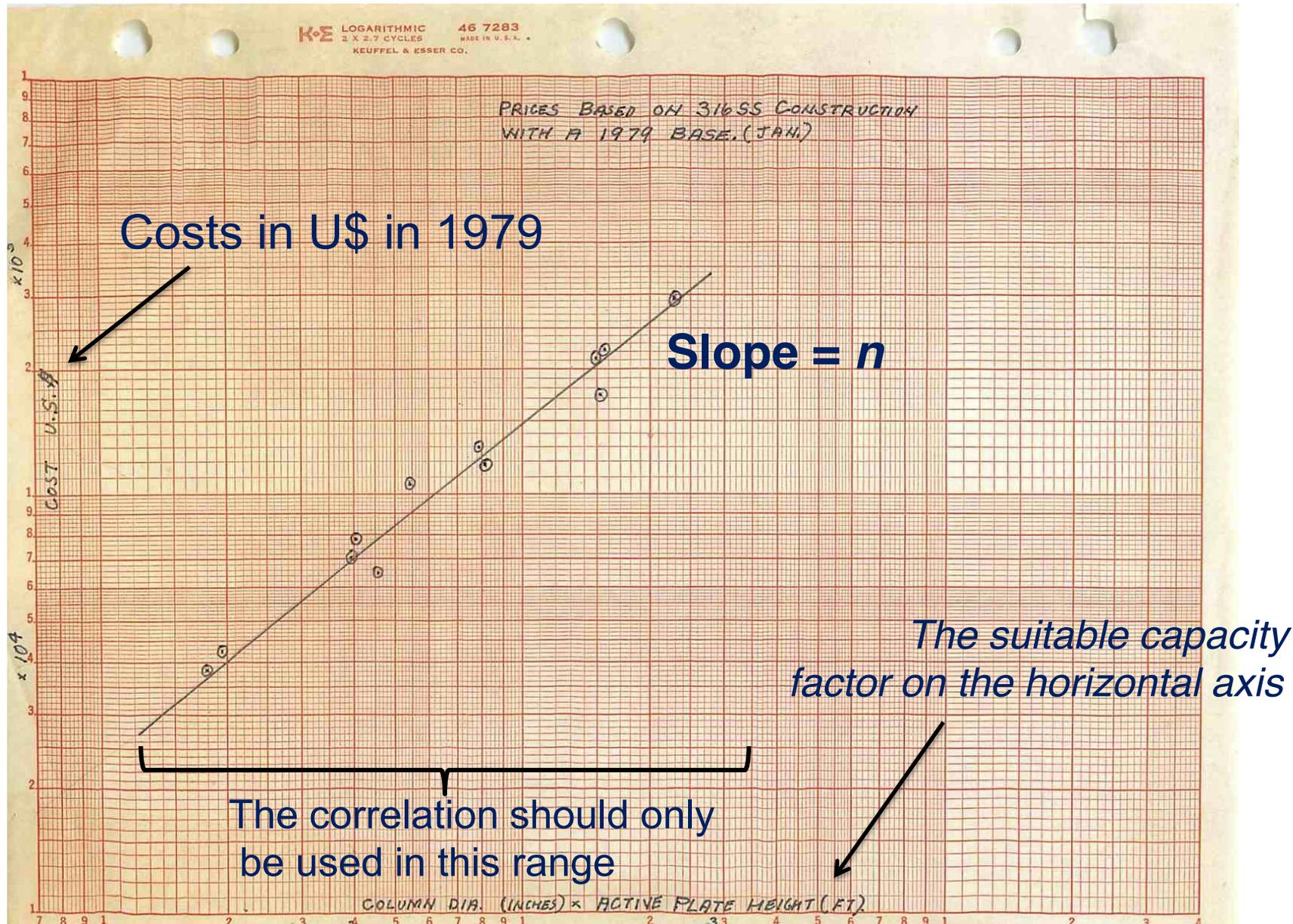
- Heat duty
- area
- number of tubes
- flow rate

What is the **exponent** for a shell and tube heat exchanger?





**Capacity factor:** the power  $n < 1.0$  (usually) !





# Cost estimation

**Capacity factor:** the power  $n < 1.0$  (usually) !

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[ \frac{\text{Factor}_A}{\text{Factor}_B} \right]^n$$

Rough guideline,  $n = 0.6$

What could limit the use of the power law?

Materials of construction

Temperature and pressure ranges

**Key point:** always look up the value of  $n$



# Cost estimation

## Example

An electric motor with capacity of 100 hp cost \$4 500. What is the estimated cost of a motor with capacity of 175 hp?

Electric motors a capacity factor of  $n=0.81$ .

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[ \frac{\text{Factor}_A}{\text{Factor}_B} \right]^n$$

$$\frac{\text{Cost}_A}{\$4,500} = \left[ \frac{180}{100} \right]^{0.81}$$

$$\text{Cost}_A = \$4,500 \left[ \frac{175}{100} \right]^{0.81} = \$7,080$$



# Cost estimation

**Inflation factor** - Converting the historical capital cost data to the time when the equipment is purchased.

Year	Marshall & Swift	Eng-News	Nelson-Farrar	Chem Eng Plant Cost Index (CEPCI)
1970	301	133	365	123
<b>1980</b>	675	300	900	261
1990	915	400	1200	358
2000	1089	510	1500	394
2000/1970	3.6	3.8	4.1	3.2

Chem. Engr.(US)

Engr-News Record

Oil & Gas J

Chem. Engr.(US)

Why don't we use the consumer's price index (CPI), which is reported frequently in the news?



# Cost estimation

## Plot of inflation data

(from: Edgar, Himmelblau and Lasdon, Optimization for Chemical Processes 2nd Ed., McGraw Hill, 2001)

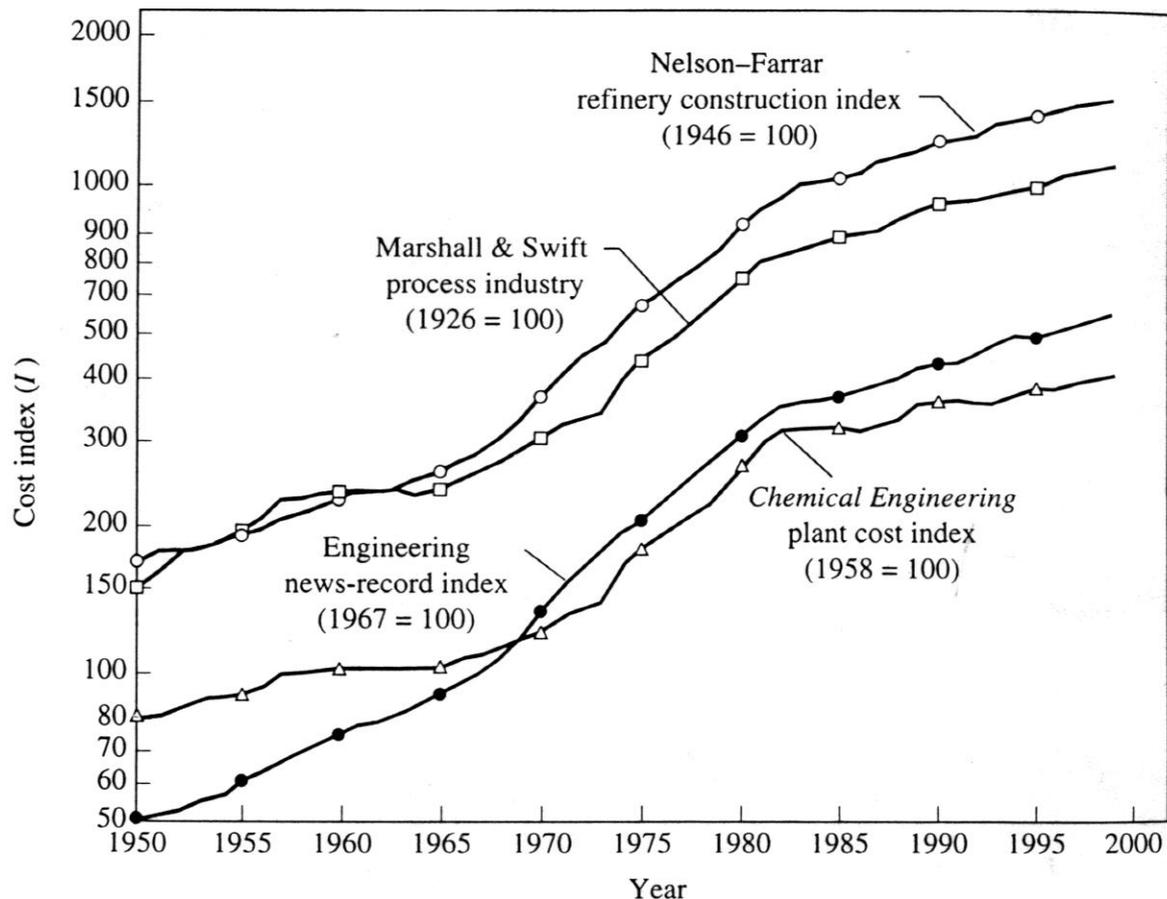


FIGURE B.4

History of selected cost indexes pertinent to chemical process construction (1950–1998)



# Cost estimation

## Example

In 1979, a distillation column cost \$65 690. What is the cost of the unit in 2011?

Marshall and Swift index in 1979 was 607 and in 2011 is was 1490.



# Sample cost estimation data

Costs are for mid-1970

ENERGY SYSTEMS & EXCHANGE: HEAT EXCHANGERS										MS = 300																																																																
Shell & Tube				Air Cooled	Tubes	Specialized																																																																				
<p>The base cost is \$8,000 for an exchanger with A = 100 m<sup>2</sup></p> <p>exponent</p>																																																																										
<p>Define basic shell and tube</p> <p>Corrections for pressure and material</p>																																																																										
<p>The correlation is valid for A = 2 to 2000 m<sup>2</sup></p>																																																																										
<p>Estimate uncertainty in ± %</p>																																																																										
<p>SHELL AND TUBE</p> <p>Floating head, 1140kPa, c/s in c/s shell, bare tube Delivered cost: standard 4.85m length, with either 1.5 or 1.9 cm O.D. tubes on square or triangular pitch.</p> <p>Pressure, MPa</p> <table border="0"> <tr> <td>2.2 : x 1.15</td> <td>7.0 : x 1.55</td> </tr> <tr> <td>2.9 : x 1.25</td> <td>22. : x 2.5</td> </tr> <tr> <td>4.2 : x 1.45</td> <td>28. : x 2.8</td> </tr> <tr> <td>5.6 : x 1.52</td> <td>35. : x 3.1</td> </tr> </table> <p>tubes in c/s shell:</p> <table border="0"> <tr> <td>Al x 1.2</td> <td>s/s 316 x 2.4</td> </tr> <tr> <td>Cu x 1.35</td> <td>s/s 304 x 2.0</td> </tr> <tr> <td>Brass x 1.3</td> <td>Monel x 3.0</td> </tr> <tr> <td>Admiralty x 1.5</td> <td>Ti x 9.0</td> </tr> <tr> <td>70-30 Cu-Ni x 1.7</td> <td>Inconel x 2.4</td> </tr> <tr> <td>Ni x 2.8</td> <td>Hastalloy C x 8.5</td> </tr> </table> <p>tubes and shell:</p> <table border="0"> <tr> <td>s/s 316 x 3.0</td> <td>Monel x 4.0</td> </tr> <tr> <td>s/s 304 x 2.8</td> <td>Ti x 13.0</td> </tr> </table>										2.2 : x 1.15	7.0 : x 1.55	2.9 : x 1.25	22. : x 2.5	4.2 : x 1.45	28. : x 2.8	5.6 : x 1.52	35. : x 3.1	Al x 1.2	s/s 316 x 2.4	Cu x 1.35	s/s 304 x 2.0	Brass x 1.3	Monel x 3.0	Admiralty x 1.5	Ti x 9.0	70-30 Cu-Ni x 1.7	Inconel x 2.4	Ni x 2.8	Hastalloy C x 8.5	s/s 316 x 3.0	Monel x 4.0	s/s 304 x 2.8	Ti x 13.0	<table border="1"> <thead> <tr> <th>Size</th> <th>Unit</th> <th>Cost 10<sup>3</sup>\$</th> <th>Range</th> <th>n</th> <th>Err-or %</th> <th>L+M</th> <th>L/M</th> <th>BM</th> <th>Comments</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Heat Transfer Area 10<sup>2</sup> m<sup>2</sup> (1076 ft<sup>2</sup>)</td> <td>8</td> <td>0.02 to 20</td> <td>0.71</td> <td>40</td> <td>2.30</td> <td>0.36</td> <td>3.14</td> <td>Fixed tube x 0.85 U-tube x 0.87 Kettle re-boiler x 1.35 Tubes only x 0.3 Expansion joint on fixed tube x 1.25 23,70,91 123,126,127 128,145,150 170,201,203 212,314,318 344,403,494 498,506,531</td> </tr> <tr> <td>0.1</td> <td>m<sup>3</sup>/s</td> <td>0.38</td> <td>0.03 to 0.3</td> <td>0.58</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>10 108</td> <td>Heat Transfer Area m<sup>2</sup> ( ft<sup>2</sup>)</td> <td>4</td> <td>0.7 to 70</td> <td>0.69</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>	Size	Unit	Cost 10 <sup>3</sup> \$	Range	n	Err-or %	L+M	L/M	BM	Comments	1	Heat Transfer Area 10 <sup>2</sup> m <sup>2</sup> (1076 ft <sup>2</sup> )	8	0.02 to 20	0.71	40	2.30	0.36	3.14	Fixed tube x 0.85 U-tube x 0.87 Kettle re-boiler x 1.35 Tubes only x 0.3 Expansion joint on fixed tube x 1.25 23,70,91 123,126,127 128,145,150 170,201,203 212,314,318 344,403,494 498,506,531	0.1	m <sup>3</sup> /s	0.38	0.03 to 0.3	0.58						10 108	Heat Transfer Area m <sup>2</sup> ( ft <sup>2</sup> )	4	0.7 to 70	0.69					
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<p>After cooler for compressor, c/s with water on shell side. excl: separator, integral piping, support stand and instrumentation.</p>																																																																										
<p>Cross bore in c/s shell. Karbate. Delivered.</p>																																																																										

$$0.02 \leq \frac{\text{factor}_B}{\text{factor}_A} \leq 20$$

$$0.02 \leq \frac{\text{Area of desired heat exchanger}}{100 \text{ m}^2} \leq 20$$

$$2 \text{ m}^2 \leq \text{Area of desired heat exchanger} \leq 2000 \text{ m}^2$$



# Cost estimation

Uncertainty in the tables is large; why?

- Covers times of economic stagnation and growth
- Covers all locations (at least in North America)
- Covers range of equipment suppliers with various technologies and efficiencies

For a specific location and equipment, a company would likely have data with less uncertainty.



# Cost estimation

Shell and tube, water cooled condenser





# Cost estimation

## Condenser in Bartek Plant





# Cost estimation

**Class exercise:** Estimate the Bare Module cost in 2000 for the following equipment.

- Shell and tube heat exchanger #1
- Floating head
- Carbon steel for shell and tubes
- $P = 1.0 \text{ MPa}$
- $\text{Area} = 70 \text{ m}^2$





# Cost estimation

**Class exercise:** Solution for heat exchanger #1



From page 5-5 in Woods (1993),

$$FOB = \$8000 * (70/100)^{0.71} = \$6210$$

$$\text{Bare Module} = 6210 * 3.14 = \$19,500$$

Capacity factor

Bare module,  $F_{BM}$

No corrections for pressure ( $P < 1.1$  MPa) or material (carbon steel) are required

Cost from 1970 to 2000 by

$$\begin{aligned} \text{Marshall Swift} &= (1089/301) \times 19,500 \\ &= \$ 70,500 \pm 40\% \end{aligned}$$

Inflation factor